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Energy Efficiency

BUILDING DESIGN ADVISOR

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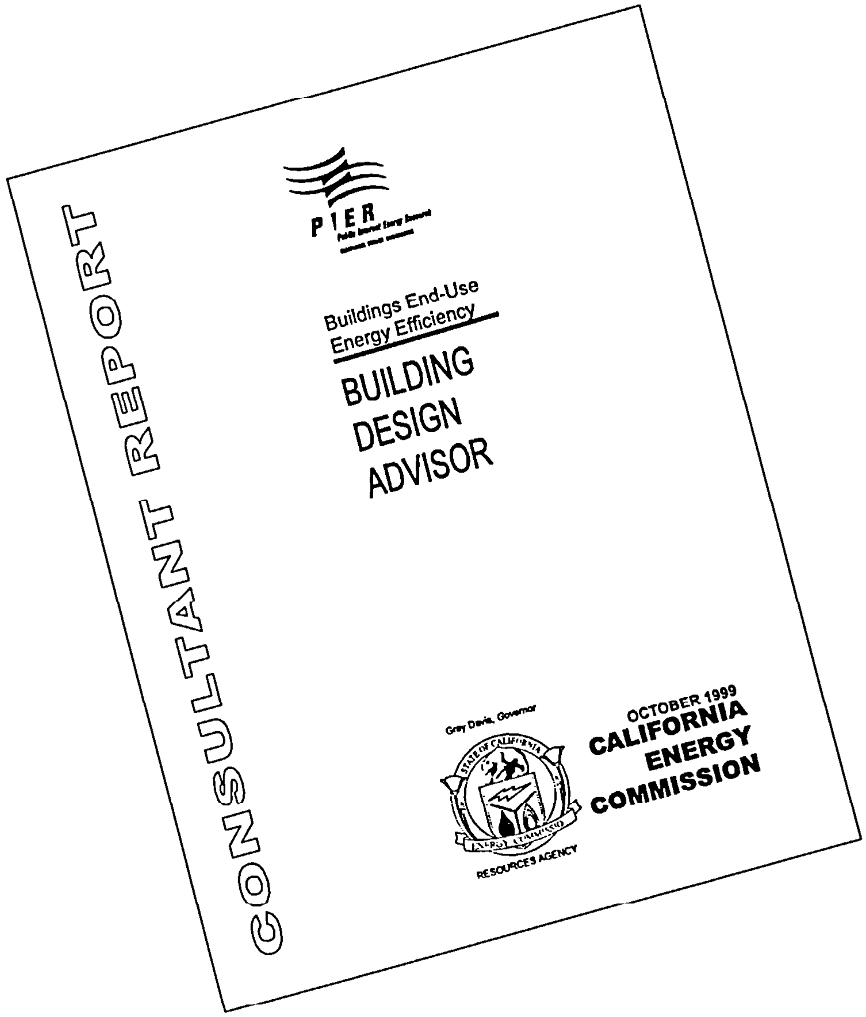

CALIFORNIA ENERGY COMMISSION

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The BDA team that contributed to this phase of the BDA development efforts includes John Loffeld (lead programmer), Smita Chandra (building model and data), Vineet Kumar (assistant programmer), Fred Winkelmann, Ender Erdem and Fred Buhl (DOE-2.1E support). The work for the BDA-based Issue-Based Information Systems (IBIS) was performed by Jean-Pierre Protzen (Professor and PI) and Ame Elliott (Ph.D. student), both from the Department of Architecture at the University of California at Berkeley.

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial / Agricultural / Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Building Design Advisor project, one of nine projects conducted by the California Institute of Energy Efficiency. This project contributes to the Buildings End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

This report is about the Phase IV efforts of the Building Design Advisor (BDA) software development project, which allows building designers to use sophisticated simulation tools for accurate performance prediction, from the early, schematic phases of building design.

The development of the BDA software started in 1994, as a one-year exploratory project funded by Southern California Edison (SCE) and Pacific Gas & Electric (PG&E) through the California Institute of Energy Efficiency (CIEE) and the U.S. Department of Energy (DOE). The objective at that time was to explore the feasibility of running multiple simulation programs from a single building representation on personal computers.

The promising results of the initial, exploratory effort resulted in CIEE and DOE adopting the development of the BDA software as a multi-year effort, toward the development of a usable tool with commercialization potential. The plan called for an initial version with links to simplified daylighting and energy simulation tools. The objective of the initial version was to elicit feedback and guidance from the building industry for the development of follow-up versions, with links to sophisticated simulation tools that are suitable for use in real practice.

After last year's deregulation of the utilities industry, the BDA project was among the CIEE multi-year projects that received Public Interest Energy Research (PIER) funds for an additional year. At that time, the initial version of the BDA software was in Beta testing. The objective of the PIER-funded project was to develop the Beta into a final 1.0 version, elicit comments and guidance from the building industry, initiate the development of the 2.0 version with links to the DOE-2 energy analysis software, and develop a strategy for the commercialization of the software.

Problem Statement

One of the main barriers in considering energy-efficient strategies and technologies in buildings is the lack of tools to assess their performance during the building design process, especially during the initial, schematic phases of building design.

To make decisions, building designers need to predict and evaluate performance with respect to multiple energy and non-energy performance criteria, such as comfort, esthetics, and economics. Moreover, designers need to predict and evaluate performance repeatedly, testing every idea with respect to energy-efficient strategies and technologies. To do so, designers need access to accurate performance simulation tools that have the required modeling capabilities.

Most of the performance prediction tools currently available, such as DOE-2 (energy requirements and cost), and Radiance (electric lighting, daylighting and esthetic appeal), are costly to use. They require significant time investment both in user learning and in their actual use. To use these programs, designers need to learn how to describe the building and its context using special keywords and syntax in text files. Learning how to prepare these input files can take several weeks to several months. To prepare a file for a particular building can take days to weeks depending on the size and complexity of the building, even for experienced users.

Another major limitation of existing tools is that they are not compatible with each other. Each tool uses a different representation for the building and its context, depending on the performance aspect addressed. A thermal analysis tool represents the building in terms of thermal barriers with hear transfer properties, while a lighting analysis tool represents the building in terms of polygons with optical properties. Designers have to describe the building repeatedly for each tool, in addition to the computer-aided design (CAD) description that they traditionally do for construction specifications.

As a result, currently available simulation tools, such as DOE-2 and Radiance, are used only marginally, in projects that can cover the associated expenses. In addition, they are used only after most of the building design has already been completed.

Objectives

The main goal of the BDA project was to develop a software environment for desktop computers that allows building designers to use multiple simulation tools easily and quickly, by automating the preparation of their input and integrating their output in ways that support multi-criterion decision making. Such a tool would allow a significantly larger fraction of the building design industry to consider the energy implications of their decisions and lead to an increased use of energy efficient technologies in new and retrofitted buildings.

This project's objectives were to:

- Bring the initial BDA software from an unstable, incomplete Beta release to a robust 1.0 version for distribution to academia and the building industry for evaluation and feedback.
- Develop an updated 2.0 version with links to DOE-2. This will demonstrate the expandability of the BDA software to include links to simulation tools already accepted and trusted by the building industry and make the BDA more appealing for use in actual projects.
- Elicit industry feedback for the identification of industry needs and desires, towards BDA versions that will be appropriate for use in actual projects.
- Prepare a commercialization strategy for widespread distribution of the software with proper user support.
- Initiate development of a BDA-based Issue Based Information System (IBIS) that will facilitate use of the BDA as a collaborative, concurrent design tool, and greatly enhance the development of links to tools that address the whole building life cycle, from design through construction and commissioning, to operation and eventual demolition.

Outcomes

- The BDA 1.0 has been in distribution since January 1999, free of charge through the Internet. To date, more than 450 reviewers have downloaded the software from the project's Web site. Approximately 150 reviewers are from academia (professors and students) and 300 are from the building industry (architects, engineers, energy consultants, etc.).
- Beta releases of BDA 2.0, with links to DOE-2, were used in workshops with architects and engineers in the San Francisco, Los Angeles, and Sacramento areas. Useful comments were elicited through extensive interactions between the software developers and the building industry participants. Comments and suggestions were organized and

prioritized based on workshop participant's input. A complete discussion of this outcome is provided in Appendix II of this document.

- The response to the BDA concept has been enthusiastic and has resulted in very useful feedback on the specific needs of building design professionals. Several university professors plan to use the BDA software in relevant architectural and engineering courses.
- A commercialization report was prepared and is presented in Appendix III.
- The design of the BDA-based IBIS was completed, with potential use scenaria and graphical user interface elements for implementation in future versions of the BDA software. This design is fully described in Appendix IV of this report.

Conclusions and Recommendations

The BDA concept has been enthusiastically accepted by the building industry and has a strong commercialization potential. Additional work is needed, however, to better shape the software toward meeting the needs of the building industry.

In its current form, the BDA software is not attractive enough to create business opportunities for commercial distribution and support. Based on the feedback from the industry, the following tasks need to be completed to bring the BDA software at a level appropriate for widespread use by the building industry. These include:

- Extensive testing of the BDA software to increase the stability and reliability of the software, and expansion of the links to the DOE-2 simulation software to address heating, ventilation and air conditioning (HVAC) design and energy cost issues.
- Development of links to commercial architectural CAD software, which will allow for graphical specification of spaces and building components in three dimensions.
- Development of links to the Radiance lighting simulation and rendering software, which will allow designers to properly address quantitative and qualitative lighting, daylighting and esthetic performance issues.
- Expansion of the BDA libraries of building components and systems to include more options, preferably actual products from manufacturers.

Abstract

This project was designed to develop a software package that allows designers to include energy-efficient options in the earliest stages of building design. This report covers the Phase IV efforts towards the development of the Building Design Advisor (BDA) software.

To make decisions on the use of energy-efficient strategies and technologies, designers need means to predict their performance under the particular context of their application, not only with respect to energy, but also with respect to other criteria, like comfort, esthetics, safety, economics, etc. The available performance prediction tools, such as the DOE-2 building energy analysis and the Radiance lighting simulation and rendering tools, are difficult to use, as they were never intended for use by building designers. They were developed by researchers, for research purposes and, until recently, could only be used on mainframes and mini computers. Today's powerful desktop computers offer unique opportunities for widespread use of simulation tools to assist with decision-making during the design process.

This project was developed to improve the use of sophisticated energy analysis tools for use in the schematic phase of building design. These analyses will make it easier for decision makers to quantitatively assess the energy and non-energy implications of energy-efficient building strategies and technologies. These tools help reduce the risk of considering efficient options in the design of new buildings or the retrofitting of existing buildings.

1.0 Introduction

The Phase IV efforts of the Building Design Advisor (BDA) software development project, was directed at developing a tool allowing building designers to use sophisticated simulation tools for accurate performance prediction during the design process. Unlike previous tools, the BDA allows performance prediction in the early, schematic phases of building design, when decisions on spatial arrangement, building form and orientation are made. These decisions have a strong impact on the energy performance of buildings and are currently made without any quantitative consideration of the energy-related impacts, because the available tools are difficult to learn and expensive to use.

The performance of most technologies depends highly on the context of their application. A low-e glazing, for example, will affect energy performance differently depending on the location of the building, the orientation of the window and the activities within the space. General statements about the energy performance of strategies and technologies are usually averages derived from simulations of the energy performance of "prototypical" buildings under various climatic conditions. Such statements are not adequate for decision making in particular buildings designed for a particular site, where the specific performance can vary significantly.

To make decisions, designers need to know the expected performance under the specific conditions of specific designs. This is true not only for energy-related performance, but for non-energy criteria as well, such as comfort, esthetics, and cost. Moreover, they need to predict and evaluate performance repeatedly, testing every idea with respect to energy-efficient strategies and technologies. In addition, they need to evaluate ideas directed toward improvements with respect to other criteria still affecting the energy performance of the building under design. To do this, designers need access to accurate performance prediction tools with the required modeling capabilities. Without these characteristics, designers will not consider new technologies and decisions will be made without considering energy implications.

Most of the performance prediction tools currently available are very expensive to use. Available tools include the DOE-2 building energy simulation (Winkelmann et. al., 1993) and the Radiance lighting simulation and rendering (Ward, 1992; Ward and Shakespeare, 1998). These tools require significant time investment in learning and using the software. To use these programs, designers need to learn how to describe the building and its context using special keywords and syntax in text files. Learning to prepare these input files can take several weeks to several months. To prepare a file for a particular building can take days to weeks depending on the size and complexity of the building, even for experienced users.

Another major limitation of existing tools is that they are incompatible. Each tool uses a different representation for the building and its context, depending on the performance aspect addressed. A thermal analysis tool represents the building in terms of thermal barriers with heat transfer properties, while a lighting analysis tool represents the building in terms of polygons with optical properties. Designers have to describe the building repeatedly for each tool, in addition to the computer-aided design (CAD) description they traditionally develop for construction specifications.

Finally, simulation tools that produce accurate results require a detailed description of the building and its context, which is not available during schematic design. As a result, most of the simulation tools are used after the building design is almost complete, when changes to schematic design decisions are very expensive to consider and implement.

1.1 Project Goals and Objectives

The main goal of the BDA project is to develop a software environment for desktop computers that will allow building designers to use multiple simulation tools easily and quickly, by automating the preparation of their input and integrating their output in ways that support multi-criterion decision making. Such a tool will allow a significantly larger fraction of the building design industry to consider the energy implications of their decisions and lead to an increased use of energy efficient technologies in new and retrofitted buildings.

The objectives of this project were to:

- Bring the initial BDA software from an unstable, incomplete Beta release to a robust 1.0 version for distribution to academia and the building industry for evaluation and feedback.
- Develop an updated 2.0 version with links to DOE-2. This will demonstrate the expandability of the BDA software to include links to simulation tools already accepted and trusted by the building industry and make the BDA more appealing for use in actual projects.
- Elicit industry feedback for the identification of industry needs and desires, toward BDA versions that will be appropriate for use in actual projects.
- Prepare a commercialization strategy for widespread distribution of the software with proper user support.
- Initiate development of a BDA-based Issue Based Information System (IBIS) that will facilitate use of the BDA as a collaborative, concurrent design tool, and greatly enhance the development of links to tools that address the whole building life cycle, from design through construction and commissioning, to operation and eventual demolition.

1.2 Background

The conceptual design of the BDA software started in 1993 and was based on a design theory that was developed in collaboration with the University of California, at Berkeley (Papamichael 1991; Papamichael and Protzen, 1993).

The development of the BDA software started in 1994, as a one-year exploratory project funded by Southern California Edison (SCE) and Pacific Gas & Electric (PG&E) through the California Institute of Energy Efficiency (CIEE) and the U.S. Department of Energy (DOE). The objective of this project (considered as Phase I) was to explore the feasibility of running multiple simulation programs from a single building representation on personal computers.

The promising results of the initial, exploratory effort resulted in CIEE and DOE adopting the development of the BDA software as a multi-year effort, toward the development of a usable tool with commercialization potential. The plan called for an initial version with links to simplified daylighting (Phase II) and energy simulation tools (Phase III). The objective of the initial version was to elicit feedback and guidance from the building industry for the development of follow-up versions, with links to sophisticated simulation tools suitable for use in real practice.

After deregulation of the utilities industry in 1998, the BDA project was among the CIEE multi-year projects that received Public Interest Energy Research (PIER) funds for an additional year (Phase IV). At that time, the initial version of the BDA software was in Beta testing. The objective of the PIER-funded project was to develop the Beta into a final 1.0 version, elicit comments and guidance from the building industry, initiate the development of the 2.0 version with links to the DOE-2 energy analysis software, and develop a strategy for the commercialization of the software.

Figure 1 presents the historical milestones of the BDA development efforts; Figure 2 presents the funds allocated since 1994.

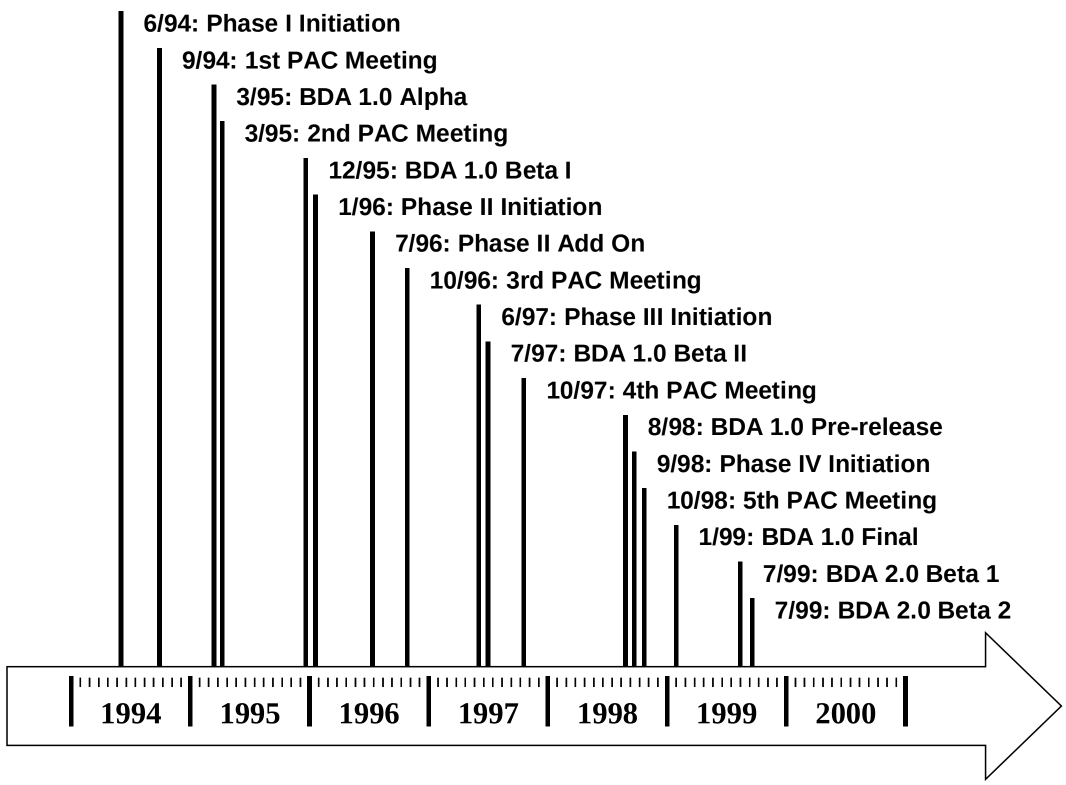

Figure 1. BDA Development Milestones since the Initiation of the Project in 1994

1.3 Technology Concept

The BDA software is based on an object-oriented representation of the building and its context. Using a combination of three interlinked databases, the BDA software supports incremental growth of the building model, maintenance of multiple alternative solutions for each building design project, and extensible libraries of building components and systems

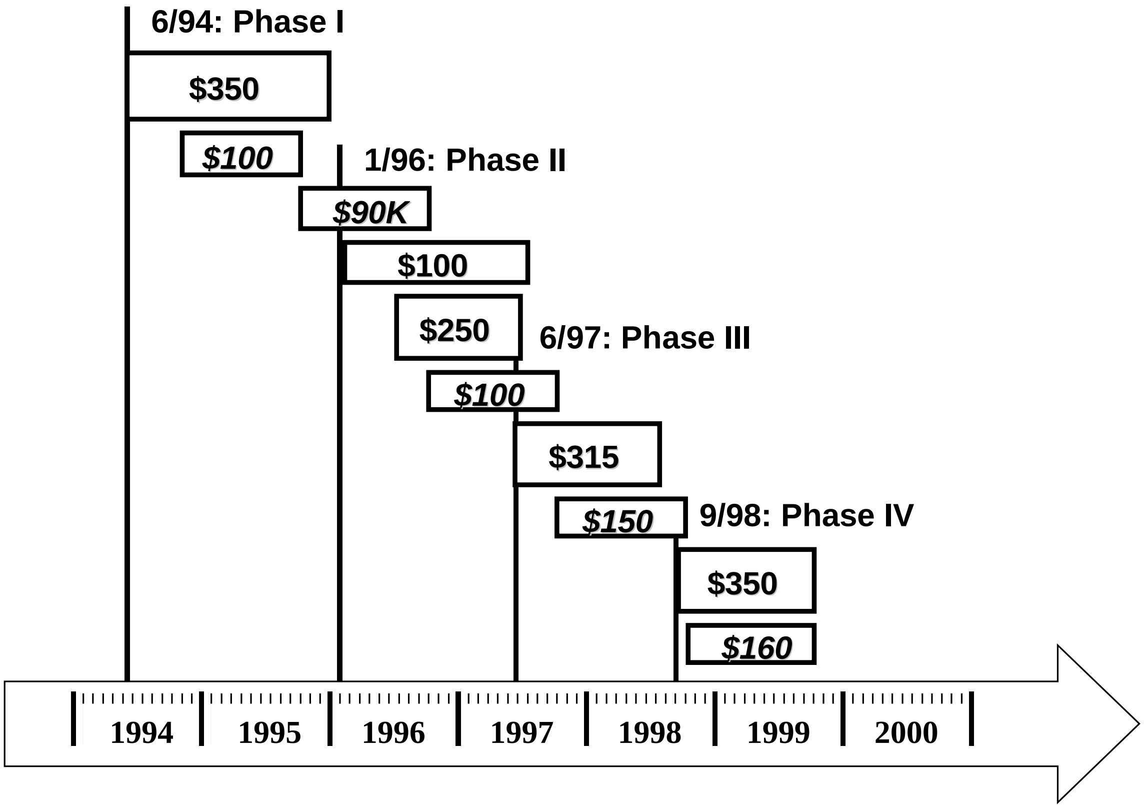

Figure 2. BDA Funding History since the Initiation of the Project in 1994

The single building representation is being developed in terms of real world objects, such as "walls," "windows" and "doors," which are automatically translated into the input requirements of the different simulation tools linked to the BDA. The output of the simulation tools is integrated into graphic displays that support multi-criterion decision-making.

Building designers have been using CAD tools, which represent drawings rather than buildings, and have no simulation capabilities beyond simplified visualization and rendering, mostly for design presentation purposes. A limited number of commercial "front-ends" and "back-ends" to energy simulation programs, such as DOE-2, have been under development during the last few years. These tools, however, are stand-alone tools that cannot be developed into an integrated design environment such as the BDA, which can support links to multiple tools and databases, allowing integrated consideration of energy and non-energy criteria.

1.4 Commercialization Potential

There are more than 60,000 registered architects in the United States and more than 25,000 heating, ventilation and air conditioning (HVAC) professionals using existing software. There is no program available today that meets the technical objectives of the BDA software and the ease-of-use objectives that would make the software use cost effective. Developing enhanced BDA software to make it attractive enough for use by the building industry, will result in business opportunities for commercial distribution and support. Detailed information on the commercialization strategy is presented in Appendix III.

1.5 Benefits to California

With appropriate licensing and marketing of the BDA software, to result in widespread use in the building design and construction industry, energy impacts are estimated at 20 kbtu / ft^2 / yr source of avoided energy use, and 0.5 W / ft^2 of avoided capacity for new buildings, as well as 7,000,000 kbtu / ft^2 / yr (source) of avoided energy use and 0.2 GW of avoided capacity for retrofitting of existing buildings.

2.0 Technical Discussion

The development of the building model used in the Building Design Advisor (BDA) software was guided by the data needs of the simulation tools to which the BDA would be being. The software was designed for easy expansion through the development of links to additional simulation tools. It uses a data meta-schema that allows the expansion of the building model in the form of data entered in a database. Special applications were developed to make this expansion quick and easy.

2.1 Completion and Distribution of BDA 1.0

At the start of the Phase IV development efforts, the initial version of the BDA software was in Beta testing, with links to two simplified simulation tools. The links were used primarily to test the feasibility of the approach. These links were:

- DElight, which computes daylight spatial and temporal distribution in rectangular spaces, and the potential for electric lighting savings through use of electric lighting dimming controls (Hitchcock 1995)
- RESEGY, which computes required sizes for heating, ventilation and air conditioning (HVAC) equipment, as well as monthly and annual energy requirements by end use and fuel type, for commercial and residential buildings (Carroll et. al. 1989).

BDA 1.0 Beta was tested by the development team and by Beta reviewers to identify and correct problems. BDA 1.0 was completed and distributed over the Internet in January 1999, through a Web site that required registering of reviewers, and supported problem reporting, and submission of comments and suggestions.

The BDA software was designed as a data manager and process controller, to manage most of the information related to the design of a building and activate individual processes to compute performance aspects as requested by the user. The BDA is already automating many tasks that are required for proper use of simulation tools and has the potential to offer any type of automation imaginable. The following sections describe some of BDA’s automation features. More details on its structure and user interface are presented in Appendix I.

2.1.1 Object-Oriented Representation

The object oriented representation of the building and its context offers unlimited potential for automating tasks that would otherwise require significant work. Moving a space, for example, will automatically move all of its walls, windows, and doors. Placing a space next to another can automatically remove or resize windows on both spaces based on the resulting configuration. This type of automation can be expanded to cover an unlimited number of possibilities.

2.1.2 BDA Meta-Schema

The BDA uses a data meta-schema to organize building components and systems, with the relationships among them and the parameters that characterize them. Through the use of the meta-schema, which is described in more detail in Appendix I, the BDA allows for incremental growth of the building model, like data in a database. Instantiating new building objects, new relations and new parameters can easily expand the BDA building model.

2.1.3 Libraries of Building Components and Systems

The BDA supports the maintenance of libraries of alternative values of every building object that is defined in the building model, such as glazings, window frames, wall constructions and finishes, and HVAC equipment. The BDA users can change the values of objects by selecting alternative options from the corresponding libraries. This approach has the potential to cover libraries of actual products, maintained by individual manufacturers and accessible through the Internet.

2.1.4 Process Control Mechanism

The process control mechanism presents a new paradigm for integrating individual simulation tools and making them interoperable. Depending on the output that the user requests, the BDA can activate process as needed, making it completely transparent for the user. The control of the processes allows the BDA to use the output of one program as input to another, allowing the whole to be much more than the sum of its parts. The RESEGY energy analysis tool, for example, cannot model daylighting and associated electric lighting controls. As part of the BDA software, however, it can be run with modified lighting schedules that reflect the electric lighting savings from daylight predicted by the DElight software.

2.1.5 Automatic Wall Segmentation

One of the major innovations of the BDA software is the maintenance of two concurrent, inter-linked models, one for spaces and one for walls and wall segments. This dual model, combined with automatic differentiation between interior and exterior walls, allows building designers to move whole spaces around without redefining interior and exterior wall segments. This is useful during schematic design in development of the spatial configuration of the building.

2.1.6 Default Value Selector

Through its default value selector mechanism, the BDA allows designers to use sophisticated simulation tools, such as DOE-2, by specifying a very small fraction of the total information required as input. This automation saves significant time and associated costs, making the use of simulation tools much more attractive than it is today. Most important, the BDA allows this automation for any number of simulation tools, addressing energy and non-energy issues.

The default value selector mechanism can be seen as the equivalent of a process that generates values for descriptive parameters. In the current version of the BDA, the default values are determined based on building type, location and space type and are taken from sources like the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Handbook of Fundamentals (ASHRAE 1993) and the Illuminating Engineering Society of North

America (IESNA) Lighting Handbook (IESNA 1993). It can be expanded, however, to include consideration of the values of additional parameters for the selection of default values, such as orientation of windows for glazings and shading options.

The concept of an expanded default value selector is identical to "advice modules," which would recommend design options towards improving specific performance aspects.

2.1.7 User Interface

BDA has only two major user interface elements, common to controlling all simulation tools: the Building Browser and Decision Desktop.

2.1.7.1 Building Browser

The Building Browser allows designers to view and edit the values of most parameters that serve as input and output to simulation tools. Default values are clearly differentiated from the values assigned by design team members. Moreover, the BDA automatically keeps track of all design decisions, by associating the names of users with all changes during their sessions with the BDA. Through the addition of an Issue-Based Information System (IBIS) the BDA can support the addition of rational arguments for and against decisions, making them transparent and retraceable. The Browser can be further expanded and enhanced to provide customized views of the building data. These views can be customized to show, for example, only the objects and parameters that are relevant to a specific simulation tool, or only specific designated parameters.

2.1.7.2 Decision Desktop

BDA's Decision Desktop allows direct comparison of multiple design solutions with multiple criteria. This is the most effective way to support multi-criterion decision-making. BDA is the only tool that allows comparison among an unlimited number of design alternatives, with an unlimited number of criteria. Further extensions to the Decision Desktop can allow automatic determination of the differences between design solutions, and sorting of solutions by any of the criteria considered, which can enhance decision making even more.

2.1.8 Customization and Extensions

The BDA database and process control mechanism infrastructure offers unlimited potential for customization and extensions. The in-depth understanding and experience accumulated so can be used to develop the BDA into a "building software development kit" available to software developers to develop applications capable of addressing specific needs of different segments of the building industry. Such applications may include additional simulation tools, specialized user interface elements, advice modules, code compliance checkers, and libraries of building components and systems.

2.2 Development of Links to DOE-2

The development of links to DOE-2 followed the standard steps for linking simulation tools to the BDA software:

- Expansion of the BDA building model to include additional objects and parameters required by the new tool with appropriate default values.
- Expansion of the BDA libraries of building components and systems to address the values of the newly added parameters.
- Expansion of user interface features that may be needed for the newly added objects and parameters.
- Development of computer code that automatically extracts the data required as input to the simulation tool from the BDA project database and formats them in the way that the simulation tool expects them.
- Development of computer code that automatically extracts data from the output of the simulation tool for inclusion in BDA's project database.

The links to DOE-2 primarily addressed the building envelope design needs, considering the early schematic phases of building design. In addition to the BDA 1.0 building objects and parameters, additional links were developed to address shading from overhangs, vertical fins and external obstructions.

The output options of the DOE-2 software cover a large number of "reports" that may contain very detailed information about energy-related performance aspects, broken down in many different ways. The initial version of the links focused on five output reports for the building and two output reports for each space. The output reports for the building are:

- Total Energy Use: The total energy required for the whole building and for an entire typical year, which includes all energy sources (such as gas and electricity) and all end uses (including lighting and cooling).
- Total Energy by Fuel Type: The total energy use broken down by fuel type (gas and electricity) for the whole building and for an entire typical year, including all end uses (lighting and cooling).
- Total Energy by End Use: The total energy use broken down by end use (lighting and cooling) for the whole building and for an entire typical year, including all energy sources (gas and electricity).
- Monthly Energy by Fuel Type: The total energy use for each month, broken down by fuel type (gas and electricity) for the whole building and for an entire typical year, including all end uses (lighting and cooling).
- Monthly Energy by End Use: The total energy use for each month, broken down by end use (such as lighting and cooling) for the whole building and for an entire typical year, including all energy sources (including gas and electricity).

The output reports for each space are:

- Annual Electric Lighting Savings: The lighting energy percent saved for each month of the year. It is computed for the specified lighting power density and electric lighting controls, based on the work plane illuminance at the center of the room.
- Monthly Electric Lighting Energy Savings: The lighting energy percent saved for each hour of a typical day in each month of the year. It is computed for the specified lighting power density and electric lighting controls, based on the work plane illuminance at the center of the room.

More DOE-2 output reports will be considered in future versions of the BDA, following the recommendations from the BDA users, reviewers and workshop participants.

2.3 Completion and Distribution of BDA 2.0

Beta versions of BDA 2.0 were made available to reviewers through the Internet since July 1999. The BDA 2.0 distribution Web site also requires registering of reviewers, and supports reporting of problems as well as submission of comments and suggestions.

2.4 BDA Workshops

Three BDA Workshops with participants from the building industry were organized in collaboration with Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and the Sacramento Municipal Utility District (SMUD). Industry participants were enthusiastic about the BDA software and helpful in specifying and prioritizing needs and desires toward bringing the software at a level that will be appropriate for professional use. Detailed results of the workshops are described in detail in Appendix II.

2.5 BDA-Based IBIS

The technical approach for the expansion of the BDA model to address the data needs for documentation of design intent and argumentation was based on the IBIS. The IBIS components and structures were analyzed with those of the BDA data meta-schema, which was then expanded to include the required additional objects, relations and parameters. A report on the design of the BDA-based IBIS is provided in Appendix IV.

The BDA software has been designed as a data manager and process controller, to manage most of the information related to the design of a building and activate individual processes to compute performance aspects as requested by the user. The BDA is already automating many tasks that are required for proper use of simulation tools and has the potential to offer any type of automation imaginable. This section refers to some of BDA's automation features. More details on its structure and user interface are presented in Appendix I.

3.0 Conclusions and Recommendations

3.1 Project Objectives

The technical objectives of this phase of the Building Design Advisor (BDA) development efforts have been:

- Bring the initial BDA software from an unstable, incomplete Beta release to a robust 1.0 version for distribution to academia and the building industry for evaluation and feedback.
- Develop an updated 2.0 version with links to DOE-2. This will demonstrate the expandability of the BDA software to include links to simulation tools already accepted and trusted by the building industry and make the BDA more appealing for use in actual projects.
- Elicit industry feedback for the identification of industry needs and desires, toward BDA versions that will be appropriate for use in actual projects
- Prepare a commercialization strategy for widespread distribution of the software with proper user support.
- Initiate development of a BDA-based Issue Based Information System (IBIS) that will facilitate use of the BDA as a collaborative, concurrent design tool, and greatly enhance the development of links to tools that address the whole building life cycle, from design through construction and commissioning, to operation and eventual demolition.

3.2 Project Outcomes

- The BDA 1.0 has been in distribution since January 1999, free of charge through the Internet. To date, more than 450 reviewers have downloaded the software from the project's Web site. Approximately 150 reviewers are from academia (professors and students) and 300 are from the building industry (architects, engineers, energy consultants, etc.).
- Beta releases of BDA 2.0, with links to DOE-2, were used in workshops with architects and engineers in the San Francisco, Los Angeles, and Sacramento areas. Useful comments were elicited through extensive interactions between the software developers and the building industry participants. Comments and suggestions were organized and prioritized based on workshop participant’s input. A complete discussion of this outcome is provided in Appendix II of this document.
- The response to the BDA concept has been enthusiastic and has resulted in very useful feedback on the specific needs of building design professionals. Several university professors plan to use the BDA software in relevant architectural and engineering courses.
- A commercialization report was prepared and is presented in Appendix III.
- The design of the BDA-based IBIS was completed, with potential use scenaria and graphical user interface elements for implementation in future versions of the BDA software. This design is fully described in Appendix IV of this report.

3.3 Recommendations

While all technical objectives for this phase have been achieved, there are several additional objectives that need to be met for the successful commercialization of the BDA software. These include:

- Extensive testing of the BDA software to increase the stability and reliability of the software, and expansion of the links to the DOE-2 simulation software to address heating, ventilation and air conditioning (HVAC) design and energy cost issues
- Development of links to commercial architectural computer-aided drafting (CAD) software, which will allow for graphical specification of spaces and building components in three dimensions
- Development of links to the Radiance lighting simulation and rendering software, which will allow designers to properly address quantitative and qualitative lighting, daylighting and esthetic performance issues
- Expansion of the BDA libraries of building components and systems to include more options, preferably actual products from manufacturers.

3.4 Commercialization Potential

More details on the commercialization strategy are presented in Appendix IV. Figure 3 shows the expected integration of tools used at different phases of building design, following the BDA software development strategy.

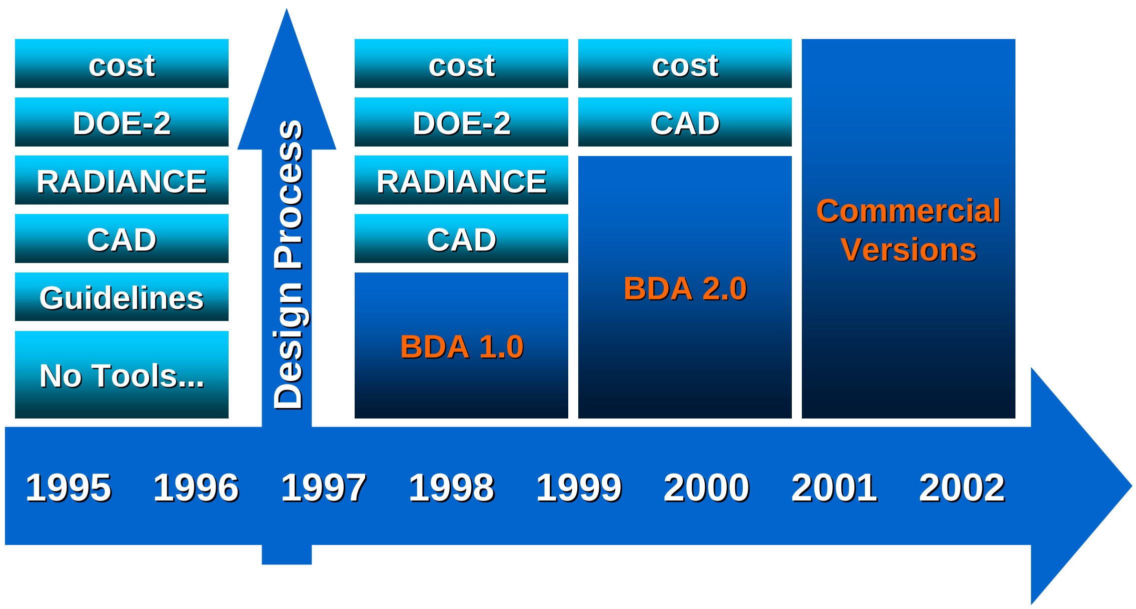

Figure 3. Vision towards commercial versions of the BDA software that will gradually include links to DOE-2, Radiance, commercial CAD and economic analyses.

3.5 Benefits to California

A survey of DOE-2 users showed an average of 17 percent energy savings through the use of the program. Such savings are currently realized by a very small fraction of the building industry that is willing and can afford to use simulation programs like DOE-2 in their current form. Software such as the BDA facilitates the use of DOE-2 and integrates it with the use of additional simulation tools will attract a much larger fraction of the industry.

The BDA is an enabling technology. It enables building decision makers to consider the use of energy-efficient strategies and technologies. Without means to understand how a particular technology will perform in a particular building, most designers will not undertake the risks of utilizing it. Once the BDA is completed, it will allow quick and easy prediction of performance aspects and easy identification of the proper technologies for their designs. With appropriate licensing and marketing of the BDA software resulting in widespread use in the building design and construction industry, the energy impacts are estimated at 20 kbtu / ft^2 / yr (source) of avoided energy use and 0.5 W / ft^2 of avoided capacity for new buildings, 7,000,000 kbtu / ft^2 / yr (source) of avoided energy use and 0.2 GW of avoided capacity for retrofitting of existing buildings.

The completed BDA software has the potential to significantly increase the value of using simulation tools by drastically reducing time requirements and associated costs. It is expected that an increased number of building design firms will adopt the use of simulation tools, which will result in increased employment of energy design professionals.

Finally, the BDA has the potential to increase employment in the software industry, by encouraging the development of links to additional simulation tools and databases, specialized user interface modules, and design advise modules.

Special benefits of the BDA software use include the long-term potential for continuous improvement in building energy efficiency through direct promotion of energy-efficient strategies and technologies.

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APPENDIX I

THE STRUCTURE AND USER INTERFACE OF THE BDA SOFTWARE

APPENDIX II

INDUSTRY NEEDS, DESIRES AND PRIORITIES

APPENDIX III

COMMERCIALIZATION STRATEGY

APPENDIX IV

BDA-BASED IBIS DESIGN

APPENDIX I

THE STRUCTURE AND USER INTERFACE OF THE BDA SOFTWARE

The BDA is composed of a central, common database that stores information about the building and its context in terms of “real world objects,” such as walls, windows, etc. This central database, or building model, is linked to a graphical user interface, a set of external databases and a set of external processes (Figure I-1). Some of the processes and databases are used for the creation and assignment of values to design and context variables, while others are used to compute the values of performance indices. The BDA automatically extracts information from databases, activates processes by supplying them with the information they need, in the form that they expect it, and stores their output in the central building model.

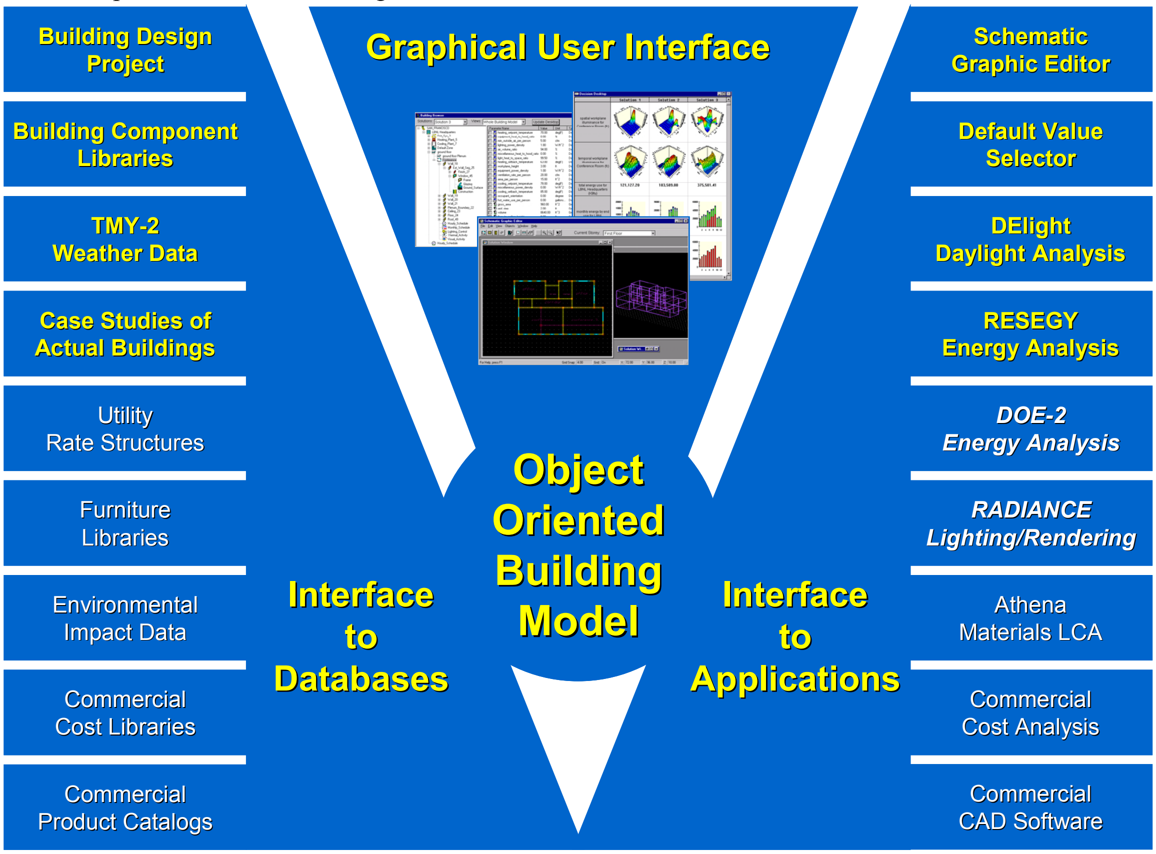


Figure I-1. The Building Design Advisor

The Building Design Advisor is composed of a central data model that is linked to a graphical user interface and multiple simulation tools and databases. Bold yellow font indicates components included in the 1.0 release. Bold italic font indicates components currently under development.

Data Structures and Libraries

The BDA development is based on extensive use of object-oriented programming, which supports modeling in terms of “objects” that are linked to each other through “relations” and are characterized by “attributes” and “methods” (Figure I-2). Following this paradigm, the BDA building representation is based on real objects, such as spaces, walls, windows, etc. as objects. However, the representation of the parameters that characterize them is not in the form of attributes. Rather it is in the form of software objects as well (Figure I-3). The same is true for the relations among building objects. In this way, the BDA building model can be expanded through the creation of new building objects, as well as new relations and parameter objects for new and existing objects.

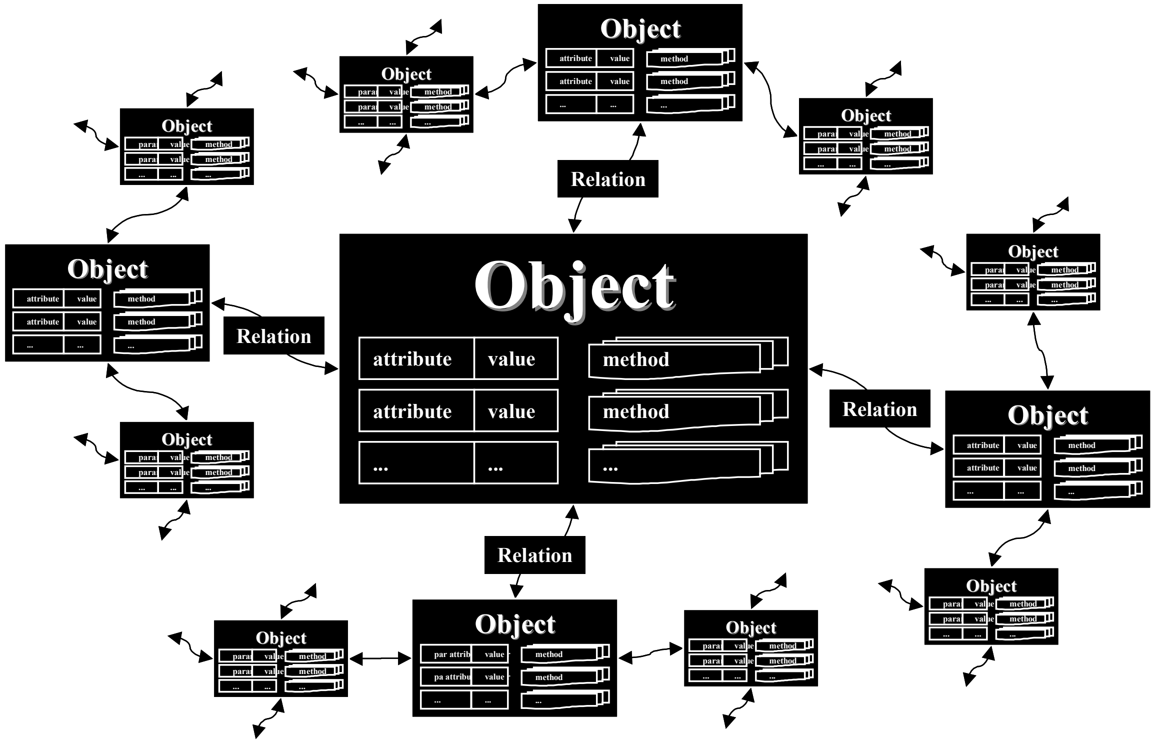


Figure I-2. Object-oriented programming supports representation in terms of objects that may be related to each other and are characterized by attributes and methods.

Another advantage of this representation is the use of attributes to store information about the parameters themselves, like the simulation tools that use them as input or output, the different units used by each for automatic value conversion, etc. This representation, referred to as “meta-schema,” is at the heart of the BDA environment and allows the treatment of the building model and the processes that operate on it to grow as data in a database (Figure I-4). A separate application has been developed to define building objects, relations, parameters, units, simulation tools, etc., as the actual building data schema.

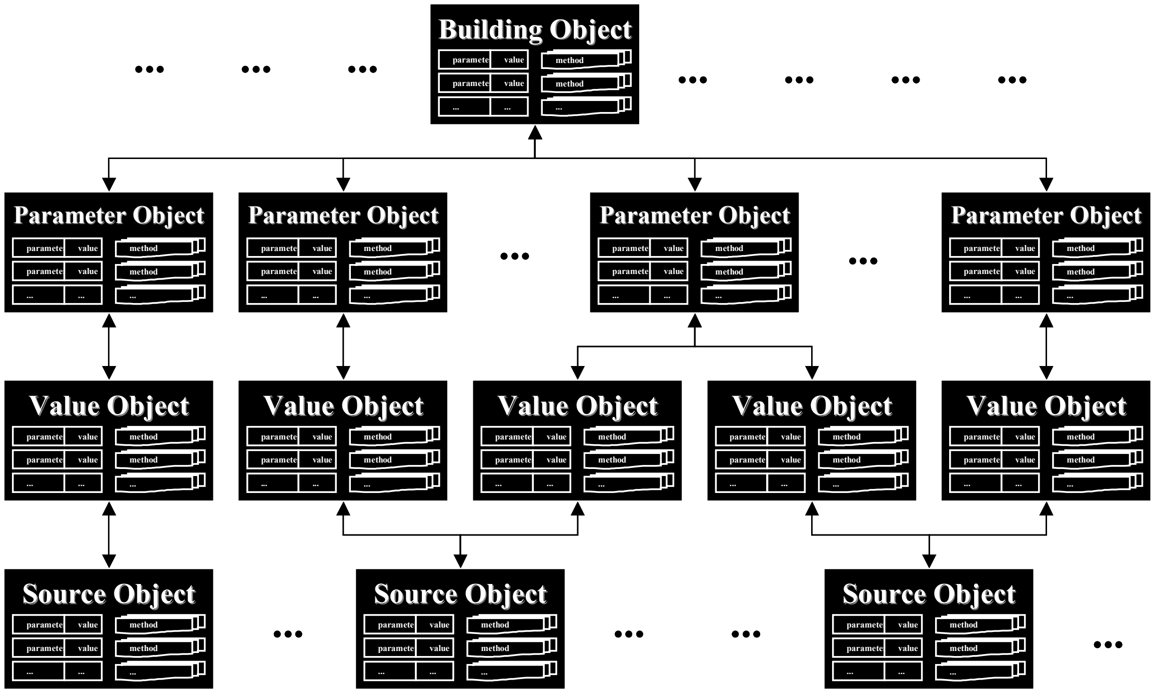


Figure I-3. The BDA uses software objects to represent not only building objects, but their parameters and values as well.

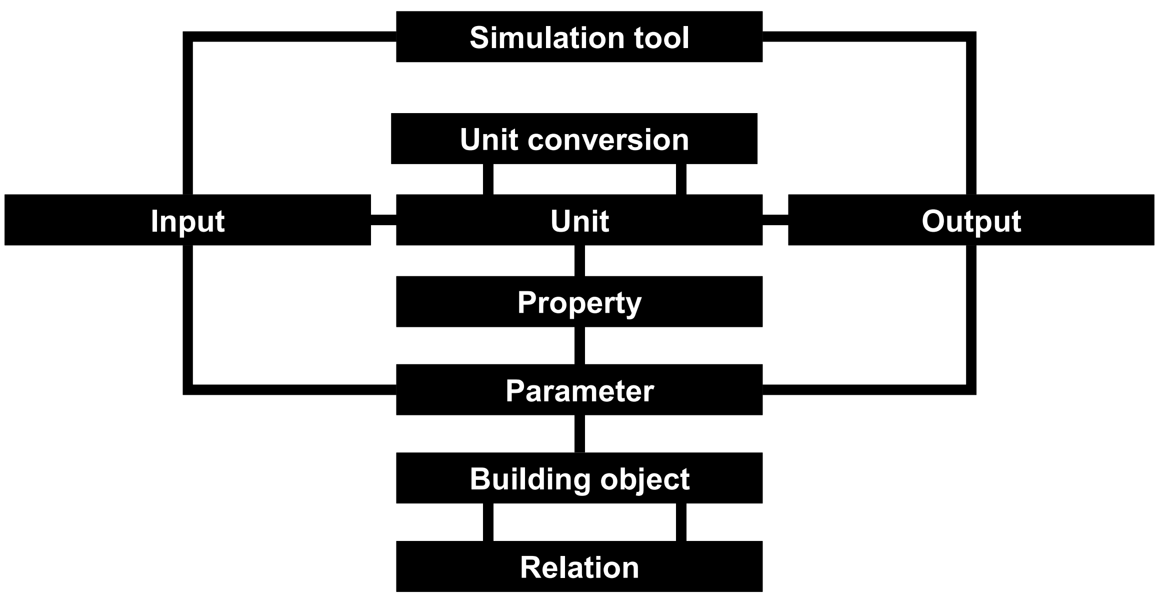


Figure I-4. The BDA data meta-schema allows expansion of the BDA building model and the analysis tools that operate on it, as if they were data entered in a database.

To support links to multiple simulation tools and address the data needs of the whole building lifecycle for future expansion, even the values of parameters are modeled as software objects. In this way, one parameter may have multiple values, which may come from different sources and at different times during the building lifecycle (Figure I-3). Acknowledging the fact that performance evaluation requires comparison among alternative options, the BDA also supports the concurrent representation of multiple design solutions as part of a "design project."

For every building object defined for the representation of the building and its context, such as “location,” “space,” “glazing,” etc., the BDA maintains a library of alternatives, such as “San Francisco,” “Conference,” “Double low-e,” etc., respectively. These libraries address the assignment of values to group of variables through the selection of names, reflecting the limited control that designers have on the values of the input variables to processes. The “San Francisco” location, for example, is translated into hourly weather data used for thermal and daylighting calculations, utility rates for the cost of energy, etc. The “Conference” room holds information about space activities that hold information about potential occupancy patterns, recommended thermostat settings and illumination levels, etc. The “Double low-e glazing” holds information about the transmittance and reflectance of the glazing, its thermal properties, etc. To create the BDA libraries of building components and systems, a separate application has been developed, which reads the data schema definitions and allows the assignment of values to their attributes for the creation of specific instances.

Process Control

When the value or a parameter requested by the user is not available in the database, a recursive logic scheme is activated to identify the process or processes that need to be activated. If the value of an object or a parameter requested by the user is not available, the BDA checks to see which processes can compute it as part of their output. It then checks to see if all of the input parameters to those processes have values. If they do, then the BDA activates the process to compute the requested value. If one or more of the required input parameters do not have values, then the BDA follows the same approach of looking for processes that can generate them as output, stacking processes for sequential execution. If the search for processes fails, then the BDA asks the user for required values and then executes all stacked processes to compute the value that was initially requested (Figure I-5).

One of the challenges in the design of the BDA has been the need to use sophisticated simulation tools from the early, schematic phases of building design, when the required details of building components and systems are not yet specified. To resolve this issue, the BDA uses a “Default Value Selection” process to assign default values to the parameters of building components and systems, based on three premises: building type, building location and space type. The selection of default values is based on building codes, standards and recommended practice, such as those provided by the American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE 1993], the Illuminating Engineering Society of North America [IESNA 1993], etc.

Acknowledging the fact that default values are the equivalent of design decisions, the BDA clearly differentiates between them and the values assigned by the designers. The default values can be reviewed and edited by the user at any point during the design process. The default value mechanism can be further expanded to include any number and type of premises. Moreover, it can be implemented as a set of processes that can include execution of simulation routines for additional information that may be needed for proper selection of defaults. The same mechanism can be the basis for processes that can provide design advise towards performance improvement.

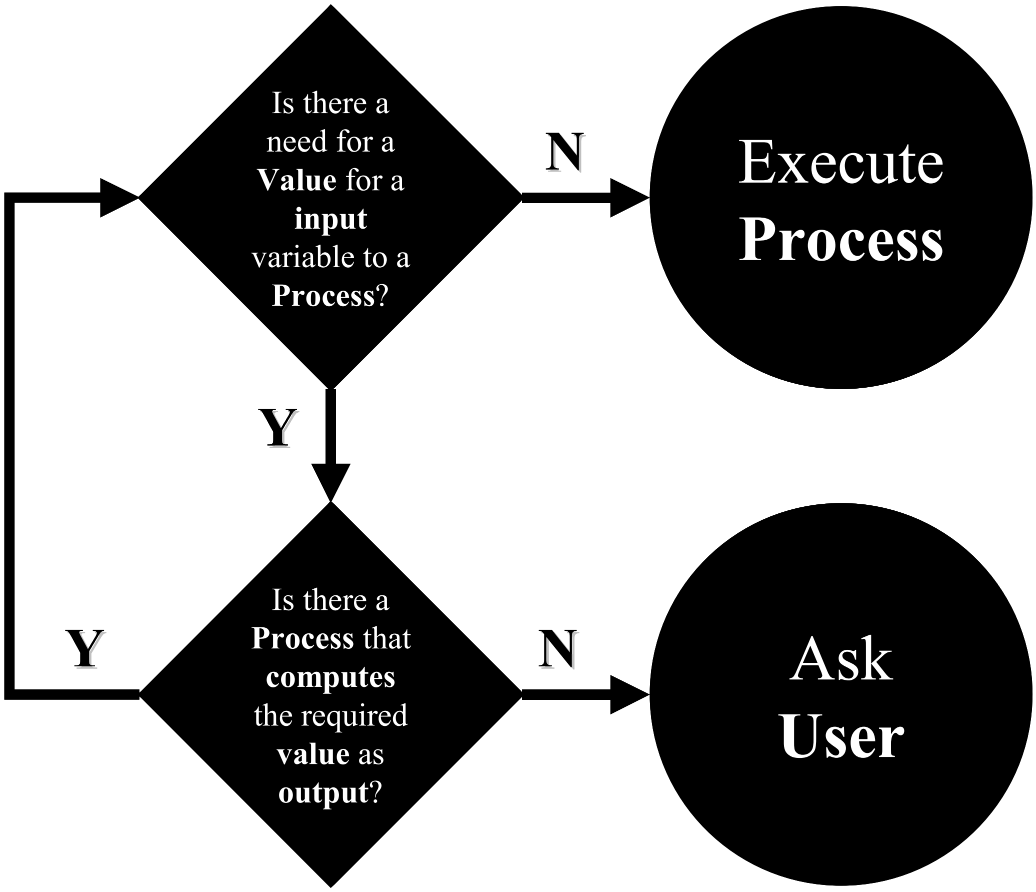


Figure I-5. The BDA main process control logic supports automatic activation of processes, as needed.

User interface

The BDA uses a graphical user interface that allows designers to review and edit all objects and parameters in a "generic way." The graphical user interface is composed of two elements: the Building Browser and the Decision Desktop.

The Building Browser supports navigation through the building model and editing of all values of building objects and parameters (Figure I-6). In the left window of the Building Browser, the user can review all building objects in a hierarchical way. When the user selects an object in the left window of the Building Browser, its "children" objects and parameters appear on the right window, along with their values, units and value sources. An icon to the left of each parameter differentiates between default values and values assigned by users, while a check box allows the selection of any number of parameters for detailed display in the Design Desktop.

The values of building objects and parameters are changed though the Object and Parameter Information dialog boxes. The values of objects are changed by selecting the name of another object instance form the corresponding BDA object libraries (Figure I-7). The values of parameters are assigned directly by the designer (Figure I-8). Only certain parameters of object can be edited by the user, following the corresponding choices in the real world. For example, the user can change the thermostat setting of a space, but not the transmittance of a glazing. To directly control such inter-related parameters, the user has to define them in sets as new library entries.

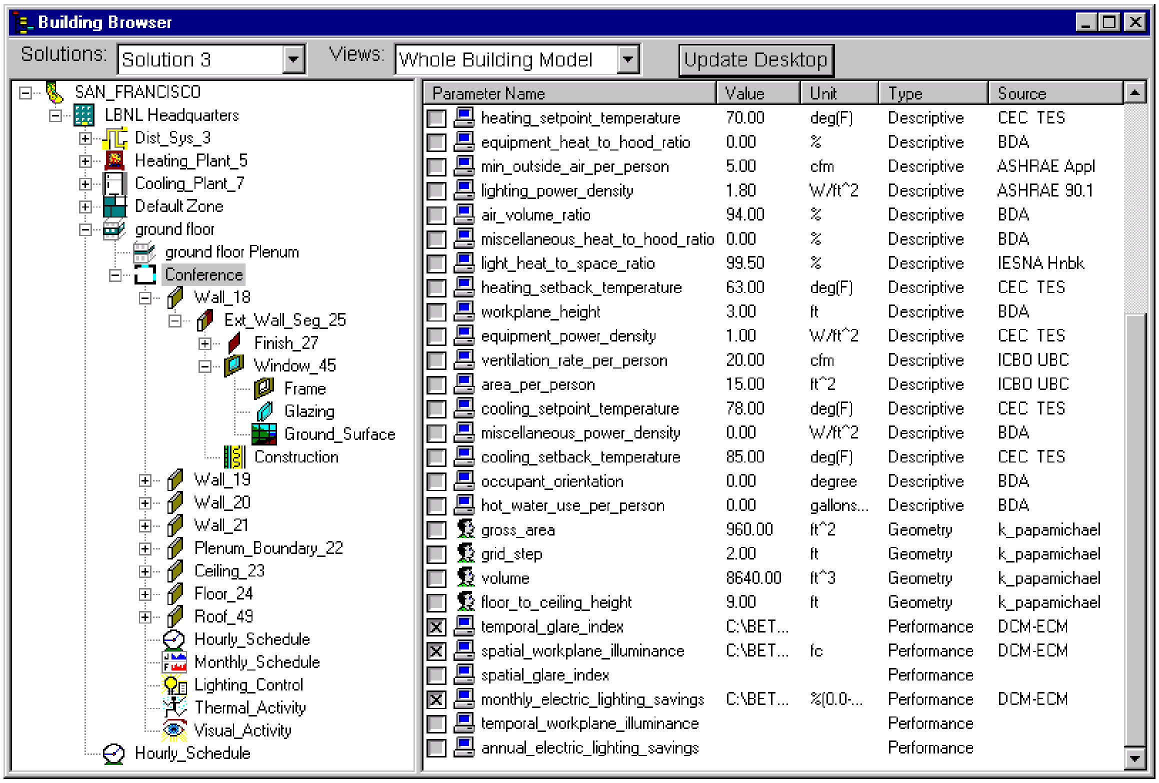


Figure I-6. The Building Browser allows designers to quickly review and edit the whole building model.

The Decision Desktop is a matrix that facilitates the comparison of multiple design solutions with respect to multiple parameters. The rows of the matrix correspond to the parameters selected by the user in the Building Browser, while the columns correspond to alternative design solutions that have been defined by the designers (Figure I-9). The BDA parameters can hold a variety of value types, ranging from single numbers, through two- and three-dimensional distributions, to images and even video. These values are displayed in the Decision Desktop cells in a variety of ways, which can be specified by the user by opening cells into their own windows for further manipulation of the data and the way they are displayed (Figure I-10).

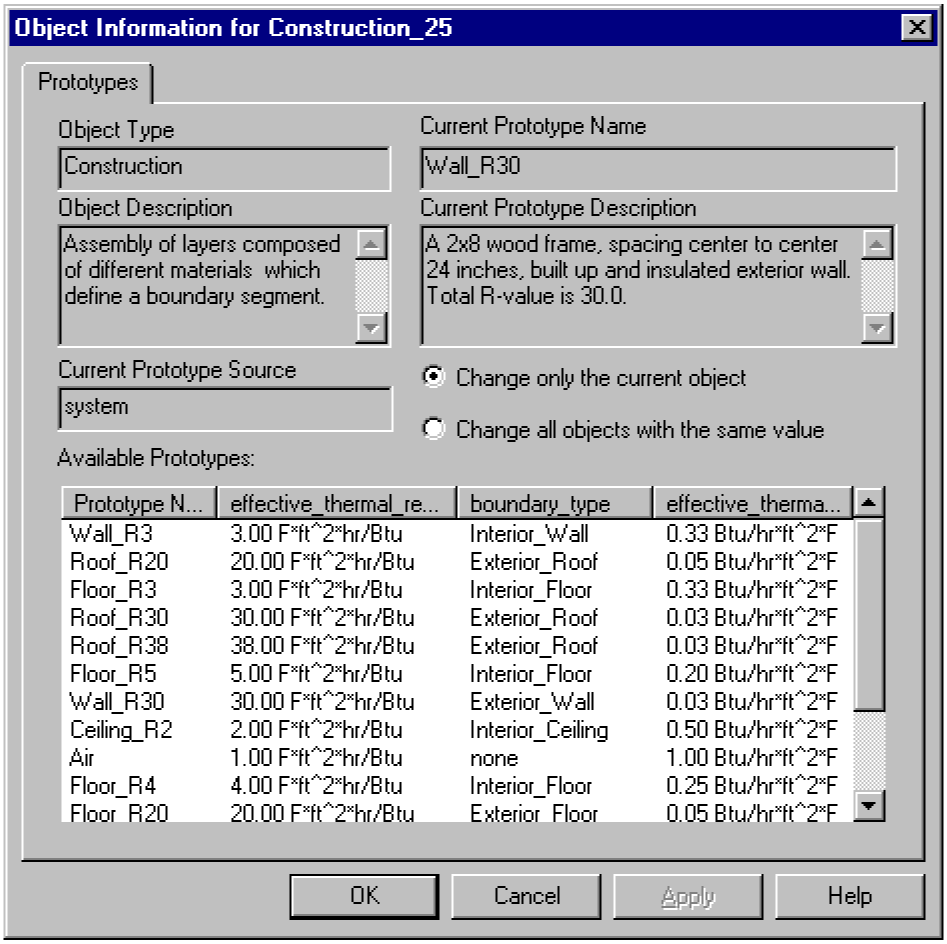


Figure I-7. The Object Information dialog box allows designers to select alternative options for building objects from the BDA libraries of building components and systems.

The Schematic Graphic Editor

The Schematic Graphic Editor (SGE) is an integral part of the BDA user interface. Following the general BDA software design, it was developed as a separate application that continuously communicates with the BDA, passing the geometric information about building components and systems drawn in it (Figure I-11).

Unlike traditional CAD packages, the SGE supports the drawing of specific building components and systems, such as "spaces" and "windows," as opposed to "lines" that represent spaces and walls in one's mind. In this way, when the BDA receives the information about a particular object being drawn, it can generate all of the relevant objects and assign default values to them.

One of the features in the design of the BDA and SGE data schemata is the concurrent representation of real world objects, such as "walls" and "windows," as well as related conceptual objects, such as "spaces." This type of combined representation allows designers to move whole spaces around, while the SGE automatically differentiates between exterior and interior wall segments for the assignment of appropriate values for wall construction.

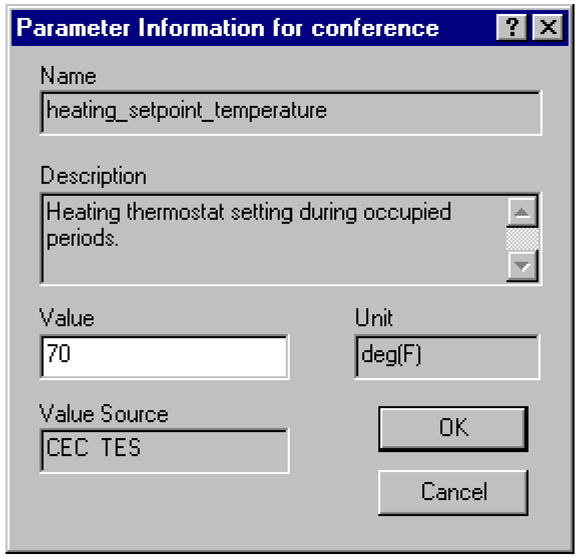


Figure I-8. The Parameter Information dialog box allows designers to change the values of individual parameters.

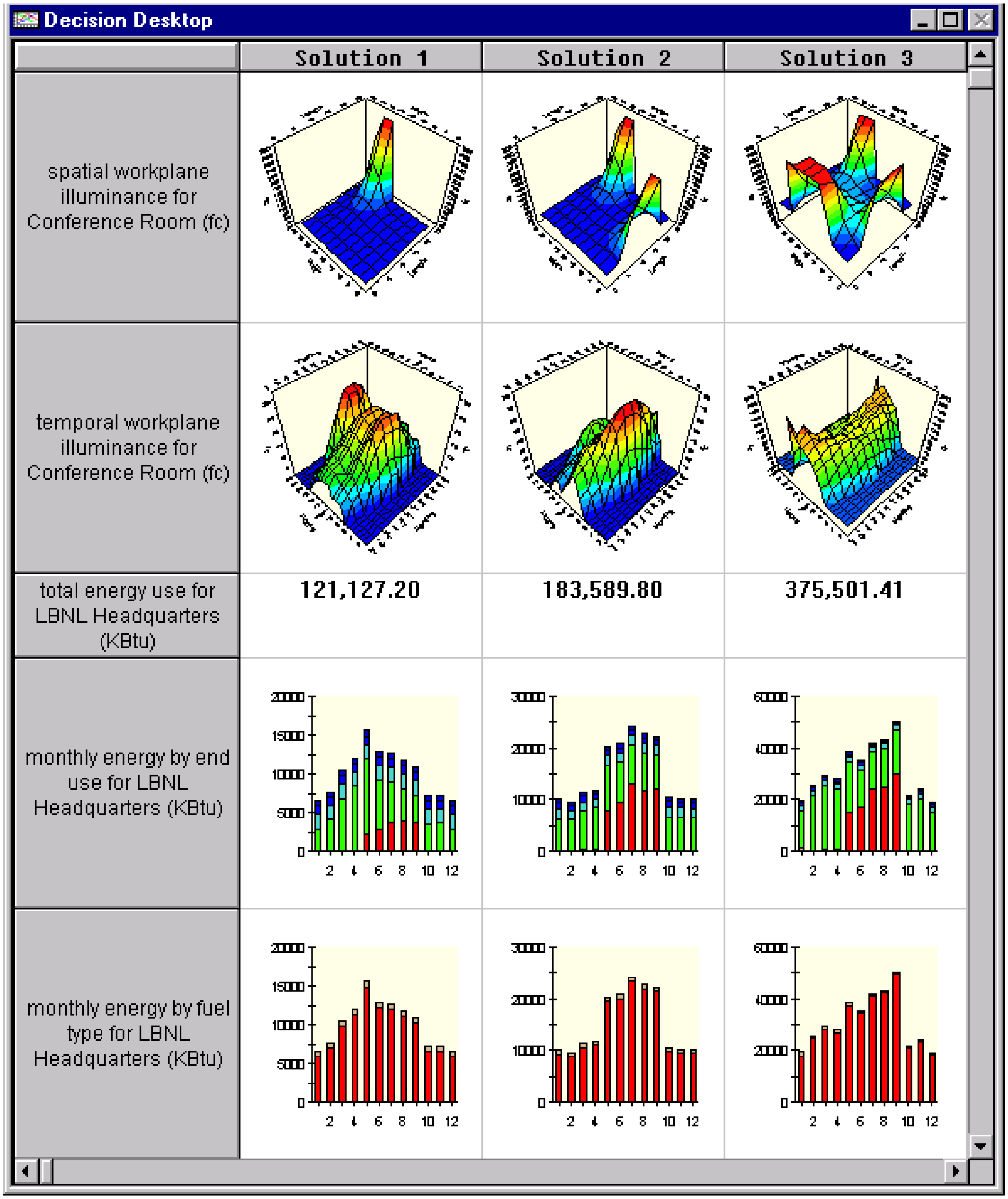


Figure I-9. The Decision Desktop allows designers to compare multiple design solutions with respect to multiple descriptive and performance characteristics.

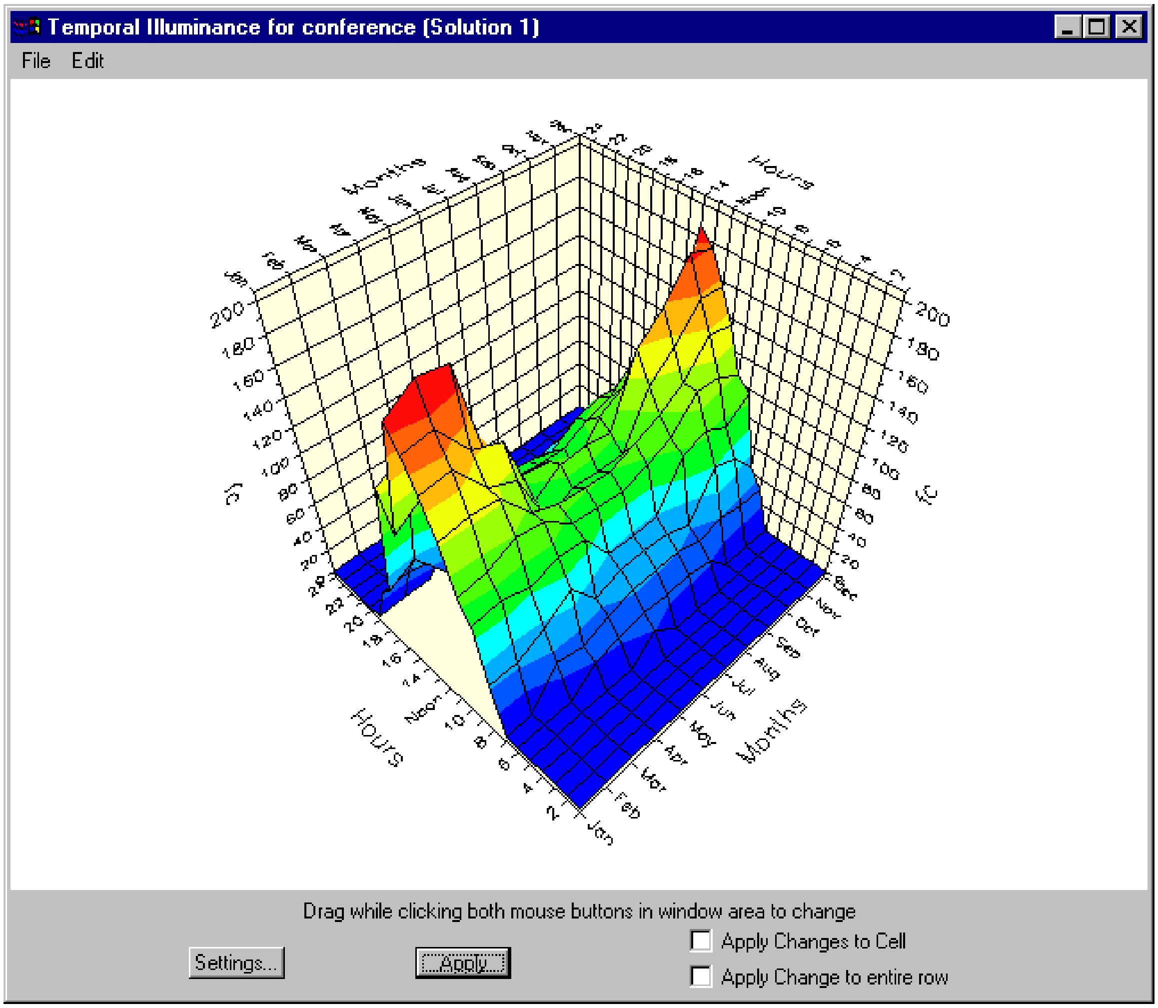


Figure I-10. The display of information in the Decision Desktop can be customized by the designer.

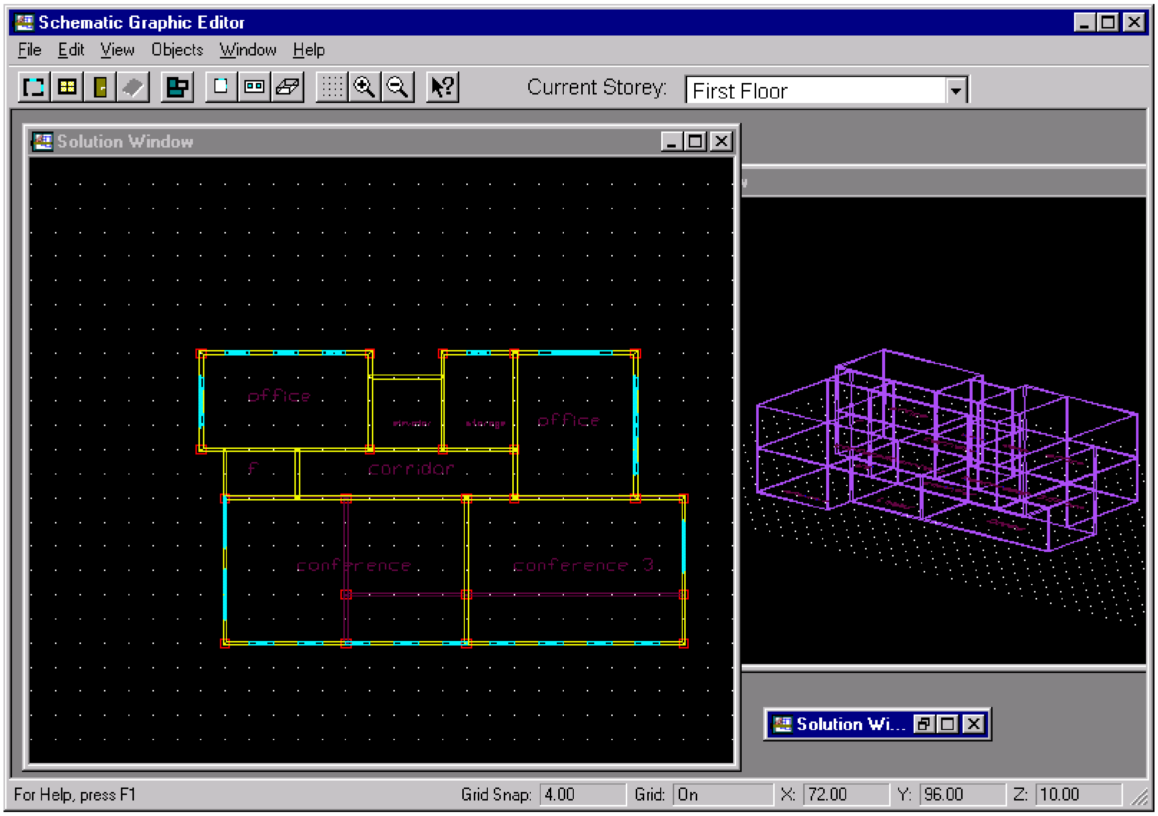


Figure I-11. The Schematic Graphic Editor (SGE) is a stand-alone application that is linked to the BDA and allows designers to specify geometric attributes of building components.

APPENDIX II

INDUSTRY NEEDS, DESIRES AND PRIORITIES

Three workshops were organized to introduce the BDA software to the building industry and elicit information about needs and desires towards making the BDA better meet their needs. The first BDA workshop was held at the PG&E center in San Francisco on July 21, 1999, with participants from eight local architectural firms interested in environmentally conscious architecture.

The workshop was organized into a morning and an afternoon session. The morning session was dedicated to the introduction to BDA software. The participants worked on their computers following the instructor in using the BDA software to address the design of simple office building. The afternoon session was dedicated to letting the workshop participants use the BDA software on their own, in a simple design exercise, while the BDA development team was available to assist and record the specific difficulties encountered by the participants. Participants were provided with forms to keep notes on problems and thoughts as they tried to use the software on their own.

The afternoon exercise was followed by an interactive session, during which the participants presented notes, externalized thoughts and focused on describing desired features towards making the BDA software most useful for them. The desired features were organized into "input" and "output" categories and were recorded on large sheets of paper that were then posted on the wall. Participants were then given 6 self-sticking color dots for each category, two red for "highest priority," two blue, for "medium priority" and two yellow for "low priority. They were then asked to indicate their priorities by placing the dots next to the features of interest on the sheets. The results are as follows, transcribed directly from the reviewers' notes.

PG&E Workshop

Features particularly well received:

- Graphs of energy performance (2 participants)
- Decision Desktop
- Ability to draw rooms and easily move them
- Easy identification of a wall as a wall by the program
- Ease of calculations, simplicity

Features particularly disliked:

- Not very flexible, needs more graphic manipulation ability
- Too text based
- Many "layers" to get to the construction data of walls etc.
- Skylights missing
- Switching between the four sections was confusing, need to improve organization
- The GUI in general was too simplified. Needs more flexibility and needs to be compact.
- Needs pan function.
- Objects don't look like what they are. Windows drawn straight appear as cross wires.

Other problems:

- Height in story dialogue box, floor to ceiling, or floor-to-floor? √
- Can't get out of new space once started √ (2 participants)
- Very slow for such a simple case study
- Cannot pick multiple objects to move or change properties (2 participants)
- "It is unlikely that any software that requires architects to redraw a building will succeed, i.e. we won't draw the same thing twice. You are currently designing a 'Building Designer'…"
- No options for external shading √

Simulations found most useful:

- Lighting energy use
- Energy use
- DOE-2
- Total BTU – "actually all graphic simulations are great."

Simulations wish list:

- Daylighting with Radiance √ (under development for next BDA version)
- Ability to set HVAC off to see interior vs. exterior temperature
- Pricing (Economics)
- Inclusion of veggies (meaning modeling of shading from vegetation) √

- Thermal mass influence
- Passive solar
- Night time cooling
- Sustainable material info √ (under consideration for next BDA version)
- Pollution prevention data √ (under consideration for next BDA version)

Suggested Simulation Tools:
- Interface with CAD
- Rendering package √ (under development for next BDA version)

Suggestions for the GUI:
- More options or ways to manipulate objects (2 participants)
- Ability to edit points and stretch walls
- Either attach to an existing object-oriented program or enable it to function like a 3-D program. Needs more graphics.
- Layer feature (meaning ability to group objects for global changes)
- Design Guidelines
- Floor area should be read out as you draw
- Simplified HVAC system interface
- Speed up time between design change and evaluation
- Other Suggestions
- Need multi-story function
- BDA tool bar should cover desktop and be behind active screens
- Highlight object in BDA should bring up Building Browser automatically √
- Object information for Construction should be in a bigger window. It needs too much parsing. Or it should be visually perceptible, maybe have a graphic interface.
- Should be able to set own defaults for windows etc. to be able to draw uniformly
- Should be able to print all defaults
- Need more than one style for windows and walls, a user library.
- Can we view KBtu/sqft?
- Ability to import a .dxf file as footprint and draw on it.
- Ability to 'pan' drawing
- Need ability to manipulate masses individually (as opposed to a single height for the whole floor etc.)
- Ability to add interior partitions for thermal mass
- Add information on commercially available glass
- Add heat system help
- Add thermal mass calculations
- Shading √
- Light shelves and Overhangs √
- Wall types, each material and values
- Key commands, shortcuts from the keyboard
- Ability to see sq. ft. of drawn area on the SGE.
- Parametric runs
- Ability to turn off HVAC and see graph of internal vs. external temperatures.
- Guidance on optimum % glass to compare daylighting vs. thermal performance.

Votes on desired input features:

(R stands for Red Dot, B for Blue and Y for Yellow)

RRRRR	Ability to manipulate volumes/ spaces graphically; ability to have varying room heights on a single story
RR	User specified window/construction styles Layers for walls Separate frames for windows.

RBY	Sunshades, complex light shelves etc.
R	External obstructions √
R	Default values need to be toned down √
BBY	Internal partitions for thermal mass
BB	Escape from new space √
BB	Pencil tool for sketching
BYY	Need a more flexible GUI
BY	Even when you put Window/wall "change all" in properties, every time you draw a new window, it takes the default instead of the user defined one. That should be avoided.
B	'Drag and Drop' function in Browser
YYY	Selection of multiple objects
YY	Incorporate keyboard shortcuts
Y	Ability to input efficiency of furnace - Code is 80%. What if furnace is 96% efficient? √
Y	Needs easier interface for browsing materials/construction
No Votes	Change outside air amount for HVAC

Votes on desired output features:
(R stands for Red Dot, B for Blue and Y for Yellow)

RRBBBY	Optimized suggestions for window areas, sill heights etc.
RRB	Shading with overhangs, effect of shading surfaces √
RRB	Effect of internal walls on thermal mass and daylighting
RR	Ability to pan/scroll SGE windows
RBY	Simulation of night-ventilation for passive cooling
RY	Simulation of thermal mass
BBY	Estimates of cost, materials, life cycle analysis
BB	Simulate heated floors; fan sensors
YY	A 'Don't remind me again' option for error messages like 'don't drag while drawing' etc.
Y	Simulate whole house fans
Y	A highlight in SGE should automatically invoke Browser √
No Votes	Distinguish thermal zones in SGE by color-coding Distinguish thermal zones in BB with color/shades/categories Information about defaults Ability to printout input file Display "% of improvement" in performance

SCE Workshop

Features particularly well received:

- Ease of creating spaces.
- Decision Desktop

Features particularly disliked:

- Not able to change orientation

Other Problems:

- When a rectangular room is created with five or more points instead of four, the program does not recognize it as rectangular and does not do DELight calculations. √
- Glazing prototypes

Suggestions for the GUI:

- Ability to Delete Solutions.
- North arrow in SGE.
- Ability to edit/scale spaces- edit points and drag/stretch walls, scale objects.
- Ability to rotate a space.
- Display sq ft of space Area.
- Ability to import CAD files into BDA.
- CAD interface
- Custom Roof
- Direct Access to properties from SGE.
- Solid surfaces representation/display
- Display the savings in a single chart
- Display the alternatives in a single chart

- Indicate Property changes in the ‘Schematic environment’.
- The overall user interface needs more work. It is hard to navigate some views.
- Add ability to draw Skylights.

Other Suggestions:

- Ability to import/export CAD file
- Interactive value grabbing with illuminance graphs
- Evaluation of performance for only certain periods of a year instead of all year round.
- Add custom glazing types
- Include Feature to be able to recover from input errors, such as changing the story floor-to-ceiling height after closing the dialog box
- Output data feature to show Cost Impact and Environmental Impact of design decisions.

Votes on desired input features:
(R stands for Red Dot, B for Blue and Y for Yellow)

RRRR	Clear stories, Light shelves, Skylights
RRBBB	Allow editing of walls and spaces.
RR	Change orientation of building
RBB	Non-rectangular spaces for daylight √ (under development for next BDA version)
RBY	Water heating input parameters
BBBY	Copy and Paste Objects
BBYYY	Add U-value to glazings and walls.
BYY	Implement doors (DOE 2.1E)
YY	Rotate single space

Votes on desired output features:
(R stands for Red Dot, B for Blue and Y for Yellow)

RRRRY	Cost of energy
RRRBY	Consider shading through building spaces
RRBYY	Sort Solutions
RBY	Display savings
BBBB	Indicate object properties in SGE e.g. air walls
BYYYY	Pollutants: NOx, SOx etc.

SMUD Workshop

Features particularly well received:

- Intuitive, easy (2 participants)
- Charts/ Graphs

Features particularly disliked:

- Not enough building/ room types
- Creates only spaces. Does not create any objects (furniture?)

Suggestions for the GUI:

- Residential bldg types and spaces with default values
- Change space size or room name
- Orientation

Simulations found most useful:

- Daylighting charts
- Energy use (2 participants)
- Savings

Simulations wish list

- $ Spent/Location (Equate energy use to actual $ based on yearly energy prices. Update annually on the Internet.)

Suggested simulation tools:

- Radiance √ (under development for next BDA version)
- Eley's Pier Project

Other problems:

- What is TMY2 in the startup dialogue box?
- Cannot go back to change story specs
- Want to go back to Project dialogue box
- Want to copy windows
- Fan capacity/generation capacity is highly off the mark
- Want to see a base default for Res. rather than Lodging
- Laptop did not indicate which choice was pre-selected in "Object Info"
- It is not clear what the R-value for the constructions is
- Different grid sizes, e.g. 100'x200' need scrolling
- While changing lighting controls, Dining with bedrooms, the program crashed

Other suggestions:

- Save As function
- Reset defaults. Parameter Change- Default Button
- Set new value as default
- Set a Title 24 default
- When someone starts typing a value in the plenum size, "Story has plenum" should be chosen automatically
- Editing space size
- Make R-value understandable
- Fins/overhangs √
- Objects besides space
- Ability to type in username for Win95
- Show SHGC for glass
- Reduce efficiency of cooling plant. As a rule, 3.8 is best, lowest is 2.61

Votes on desired input features:

(R stands for Red Dot, B for Blue and Y for Yellow)

RRR	More Building types and spaces, especially Residential
RB	'Save As' function under Project menu
RR	Change orientation of building
RY	Move/ change Names of spaces
RY	Vary heights of plenums/ spaces in the same story
R	Overhangs and fins and external obstructions √
R	Edit spaces in SGE
R	Enter spaces alternatively by specifying dimensions
BBY	Change Orientation
BB	Simulate Photovoltaic systems
BB	Simulate sloped ceilings/roofs, domes etc.
BY	Simulate Skylights
B	Go back and change the initial building information
YY	HVAC/Duct Specs esp. Residential in conditioned/unconditioned spaces
YY	Use Title 24 EER or SEER along with COP
Y	Copy objects and paste them
Y	Multiple distribution systems
No Votes	Reset 'default' values

Votes on desired output features:

(R stands for Red Dot, B for Blue and Y for Yellow)

RRRRB	Break down of end use further, e.g., break down Cooling into Convection/conduction, Solar heat gain, Internal loads, etc.
BBBY	R-value and U-value in libraries
RBYY	Show area of spaces and whole building
BBBY	SGE scrolling, zooming out; ability to change grid size
BB	Show space type (along with name)
BYY	Compare different projects
YY	Open different projects at the same time

APPENDIX III

COMMERCIALIZATION STRATEGY

The Vision

Architects implicitly consider the conditions of the interior environment when they design a building. However they lack tools to know with any precision what the actual energy needs for lighting, temperature and air quality control are going to be. After they design the building they rely on mechanical engineers and lighting designers to determine how much heating, air conditioning, and lighting will be needed to make the building comfortable and usable. Those engineers and designers then specify the mechanical systems and the required capacities.

If they had the right tool, architects could design energy and lighting efficiency into the building from the beginning of the design process, reducing the capacity requirements or perhaps even the need for heating and/or air conditioning, as well as the extent of lighting systems use. A more energy efficient design can reduce costs of construction and/or operation, and create a more pleasant environment for the occupants. It can also serve a broader social purpose by reducing the use of carbon based energy sources.

The Building Design Advisor (BDA) software can be that tool. When completed, BDA will link an object oriented CAD application to at least two powerful modeling programs, DOE-2 and/or EnergyPlus and Radiance. (Energy Plus is currently under development as a replacement to DOE-2.) DOE-2 and EnergyPlus compute the energy requirements of a building and Radiance computes lighting and daylighting quantities, also producing photometrically accurate images. BDA will provide its own object oriented graphic editor, and/or links to object-oriented CAD programs, such as the newly released Architectural Desktop software by AutoDesk. It will allow building designers to graphically describe the geometry of the building and its context and predict lighting and energy performance very early in the design phase by automating the preparation of the input to DOE-2 and/or EnergyPlus and Radiance. BDA automatically provides default values for required information, providing the means for quick and easy analyses when the building design is still very flexible.

Market Size

Initially, BDA is intended for use by architects and design decision makers, and secondarily by mechanical engineers, lighting designers, energy specialists, and others involved with energy and lighting issues in buildings.

There are more than 60,000 registered architects in the United States. While many of them still use manual drafting techniques, the use of CAD (computer aided drafting) programs is continuously increasing. There is a variety of CAD systems currently in use, such as AutoCAD, Form-Z, ArchiCad, Architrion, and the newly released Architectural Desktop, which uses an object-oriented representation of building components and systems, like the BDA. While “CAD operators” have been the main users of such programs, younger architects are becoming increasingly competent with the technology from corresponding courses in architectural schools. Architects, like most professionals, have computers on their desks at least for email, word processing, and web access. As time goes on architects will rely more and more on these computers for design work.

There are about 50,000 heating, refrigeration, and air conditioning engineers in the United States. More than 25,000 of them already rely on software programs such as HAP from Carrier, MarketManager from SRC Systems, Right-Suite from Wrightsoft, and System Analyzer from Trane, to design HVAC systems for buildings.

There are many trade associations that have an interest in energy issues in buildings, such as:

- The American Institute of Architects
- The American Society of Heating, Refrigeration, and Air Conditioning Engineers
- The International Association of Lighting Designers
- The North American Insulation Manufacturers Association
- The Energy Efficient Building Association
- The California Association of Building Energy Consultants

- The Association of Energy Services Professionals
- The National Fenestration Research Council

Competition

There is no program available today that meets the need that BDA is designed to fill, no relatively easy to use program that links an object oriented building representation to multiple powerful analytical engines. There are programs that help professionals evaluate buildings for energy and lighting characteristics, and that enable them to design energy and lighting systems. The ones that provide the most reliable information, such as DOE-2 and Radiance, are hard to use, requiring extensive training and time-consuming preparation of input and interpretation of output. While there are a few front and back ends to the DOE-2 simulation engine available for personal computers, they only address user interface issues and only for the DOE-2 engine. They do not address the data management needs and process control issues for multiple tools and it is not clear that they can be easily modified to do so. None of the energy simulation tools, other than the HVAC design programs mentioned above, have more than a few thousand users; most have much less. The market is fragmented and most users, outside the HVAC industry, are energy specialists and researchers.

Advantages of BDA

There are several advantages of the BDA, compared to the tools that are currently used in the market. Here are the most prominent ones:

- Use of a database management system to store the information about the building and its content.
- Use of an object-oriented approach to representing buildings that supports quick and easy expansion of the building model to accommodate the data needs of additional simulation tools and databases to be linked in the future.
- Maintenance of multiple designs for each project, which facilitates comparison among alternative design options.
- Generic user interface that allows use of any number of tools in a consistent way, without need for specialized interfaces for different tools.
- The ability to use the output of one program as input to another.
- Potential to greatly facilitate the development of third party tools through the addition of an Application Programming Interface (API).

BDA uses a single building representation model to drive multiple modeling tools. When linked to Radiance and DOE-2 it will analyze energy and lighting. When EnergyPlus is ready to use, it can easily be linked to the BDA as well. BDA can also be linked to an engine that will check for code compliance. As it becomes established, BDA can be linked to more, otherwise independent, tools, which can provide users with even more information about the building. Output from one analytical engine can become input for another. When linked to an HVAC program the HVAC engineer can design those systems directly from the architect's original object oriented architectural drawing, without the need to input any new information.

The BDA database management system can support multiple concurrent users operating over local and wide-area networks, which will allow future versions of the BDA to support collaborative design. Moreover, the BDA data schema for the representation of the building and its context has been designed to support the data needs of the whole building lifecycle, which will allow future versions of the BDA to be linked to tools that address construction, commissioning, operation, retrofit, and demolition.

Acceptance of BDA

There is a great deal of professional interest in BDA. The 1.0 and 2.0 Beta versions of the BDA software have been presented to a large number of architects and other industry professionals on many different occasions. Presentations have occurred at conferences and conventions, in LBNL offices, in classrooms, and via the World Wide Web. The response has been positive and enthusiastic and demonstrates that architects will respond very positively to an easy to use simulation tool that gives them accurate energy and lighting information early in the design process.

The most important recent conferences and conventions were:

- American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Summer Meeting, Seattle, WA, June 1999
- CAAD FUTURES, Atlanta, GA, June 1999
- American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Winter Meeting, Chicago, IL, January 26, 1999.
- International Building Performance Simulation Association (IBPSA) Software Demo/Expo, Chicago, IL, January 23, 1999.
- Thermal VII Conference Workshop, Clearwater, FL, December 6, 1998.
- National Convention of the American Institute of Architects, San Francisco, CA, May 15, 1998.
- International Daylighting Conference, Ottawa, Ontario, Canada, May 10, 1998.
- ACADIA 96

The BDA software won a 1998 Green Design Leader Award from the Committee of the Environment, S.F. AIA in Partnership with the Pacific Energy Center.

On at least twenty occasions in the last several years, industry professionals have visited the LBNL offices to view the program. Visitors came from US, Canada, Netherlands, Brazil, Germany, Israel Hong Kong, and Finland. Many of the visitors were architects. Among the visitors was Don Holte, the President of ASHRAE.

Michael Holmes, Associate Director of Ove Arup & Partners, one of the largest consulting companies in the World, has expressed a strong interest in using the BDA framework to integrate the simulation tools used by Ove Arup architects.

BDA has been the subject of articles in a number of technical publications as well as in trade publications such as Building Design and Construction, and ARCHITECTURE (twice).

There has been much interest from academia as well. Approximately 150 professors and Ph.D. students have downloaded the BDA software from the Web. Even early beta versions of the software have been used successfully in the classroom for demonstration of building science concepts. Students at the University of California at Berkeley with no background in building science, lighting, energy, etc. were successful in using the BDA software to guide them towards designs that met daylighting and energy goals. Several professors plan to use BDA 2.0 in their courses.

Since the release of BDA 1.0 through the Internet, more than 450 persons have downloaded the software, approximately 150 of which are academicians (Professors and students) and 300 from the building industry (architects, engineers, lighting designers, energy consultants, etc.)

Completing a commercially releasable product

The product is currently in its 2.0 version with links to DElight, a simplified daylight analysis tool, and DOE-2, a sophisticated building energy simulation tool. Links have not yet been built to Radiance. To be commercially viable it needs those links in place, as well as links to a commercial CAD package, like Architectural Desktop. Moreover, it needs to be more robust. While researchers and specialists are willing to work with a product that is somewhat unforgiving of user error, architects will expect a more robust, more bulletproof program such as the others they find on their Windows desktop.

When this work is done, BDA will be ready for commercial release. After it has been in the market place it will be ready for another round of improvements based on the comments and suggestions generated from real projects. Future releases will expand BDA's functionality to support collaborative distributed use, i.e. multiple concurrent networked users, as well as links to additional tools and databases. The development of an Application Programming Interface (API) will support the development of third party modules.

Pricing

We reviewed the prices charged for Architectural Desktop (about $5000) and for the commercial HVAC programs. We believe that a license for BDA, and its linked engines, DOE-2 and/or EnergyPlus and Radiance, should initially be worth somewhere from $795 to $1495 in the marketplace with an annual maintenance charge of about $200. The maintenance charge would provide, in addition to support, the right to buy further releases and upgrades at a deep discount.

Sales volume

Our sales forecast is based on sales of HVAC system design software and assumes that Architectural Desktop will reach an installed base of 10,000 architects. We believe that BDA Suite (BDA linked to DOE-2 and/or EnergyPlus and Radiance) could sell between one and two thousand units a year and build to an installed base of 5000 units within three years. If the BDA Suite achieves a base of 5000 users, it will become the standard and its growth will accelerate.

Commercialization: the goal

The goal is to find a substantial commercial software publisher who will license the BDA Suite and market and support the product to the architecture and heating and air conditioning engineering markets. When agreed revenue goals are reached, the licensee will take responsibility for future development of BDA (but not of DOE-2, EnergyPlus, or Radiance). The exclusive license will include well-crafted performance guarantees so that rights can be withdrawn from the licensee for non-performance. The purpose of exclusivity will be to give the licensee a strong financial incentive to invest in marketing, support, and development.

If the publisher could sell 1000 units a year for $995, that would be a $1 million business. At that level the publisher could market and support the product and make a profit. It might not be sufficient to fund enhancements and new features to BDA, so the public sector might have to continue to fund development. Of course the public sector would remain responsible for DOE-2, EnergyPlus and Radiance. The public will benefit as the use of the software reduces energy consumption and energy consumption externalities. When revenue grows to $2 million a year, the publisher will be able to take over development of BDA.

Commercialization: the path

We need to continue to engage in market research. We need to deepen our understanding of the customer's needs. We need to improve the user interface through testing. We need to increase the reliability and robustness of the software by observing problems that arise from actual use. We need customer feedback to refine the feature set. We need to evaluate the level of interest in the product and come up with evidence as to what customers are willing to pay for the product. We need to find out if there are specialized niches and professional or trade associations who have a strong interest in the product and who would help us, or our licensee, to market it.

The market research to date has been done through conference and convention presentations, presentations at LBNL offices, feedback from users who have downloaded the product from the website, and classroom use. Much of this was described above in the Acceptance Section. A great deal of useful feedback was obtained from these various presentations. This research will continue.

We will continue to present the products to LBNL visitors and we will seek opportunities to popularize the BDA software in the building industry.

We will continue to look for opportunities to popularize the BDA software in academic environments. Most of the professors that have downloaded the BDA software have expressed an interest in using it in the classroom. We expect many of them to use the BDA software in their courses starting in fall 1999. Classroom use will give us feedback and debugging. It will create a user base for the program and will give us endorsements that we can use to gain more users and to gain a commercial presence for version 2.0.

To date more than 450 persons have downloaded BDA 1.0 from the web site since its release in January of 1999. As more people use it we will obtain more information about the market for the program and gather more user response about its features, benefits and interface.

Commercialization: the candidates

We will begin to look for commercial licensees. Initially this will be done by directly approaching firms that are in related businesses.

Candidates would be firms that already have commercial products serving some portion of the market, such as HVAC simulation products, energy code compliance products, object oriented CAD products that are sold to architects or engineers, and firms that are already selling products or services associated with DOE-2 or Radiance.

- GeoPraxis. CEC has recently funded a private firm, GeoPraxis, which is planning to develop a product that will provide a similar functionality to BDA. It differs in that it is narrower in scope, addressing only energy issues. It is similar in that it wants to address issues during the early, schematic phases of building design, through links to a commercial CAD software package. Within the next three months we will make contact with the firm to see if there is any benefit in us coordinating our efforts, to see if they can give us any advice and/or if they would like to license BDA.
- AutoDesk. In that same period we will set up a meeting with the product manager of Architectural Desktop at AutoDesk. Obviously if BDA is successful it will aid the market acceptance of Architectural Desktop. We want to learn more about the market for their product, get their advice, and find out if they know of any firm that might be interested in licensing BDA.
- HVAC and CAD software firms. After these two meetings have taken place, and within the next six months, we will approach one or two of the local firms with HVAC software packages to find out about that market and to see if they would be potential licensees of BDA. Moreover, we will contact additional CAD companies, like Bentley and Graphisoft.

These business meetings will give us practical business information. With a better overview of the commercial marketplace, its challenges and opportunities, we will be able to refine and target our commercialization strategy. We will develop leads and business contacts. As we improve our product and our market knowledge we will expand our circle of contacts until we locate a commercial licensee.

Conclusion

In review, our goal is to license the BDA Suite to an exclusive licensee that is a substantial firm that can market and support the product to the architecture and heating and air conditioning markets. It will be achieved through continued market research and testing, the further development of version 2.0, and marketing activity to software publishers until we locate a suitable licensee.

APPENDIX IV

BDA-BASED IBIS DESIGN

An Issue-Based Information System (IBIS) is a means of documenting design rationale, or reasoning related to design decisions. The technique was originally developed in the 1960's as a paper-based system for deliberating decisions [Kunz and Rittel 1970]. In recent years, several computer-based IBIS's have been implemented to aid the decision-making process in various domains, including space-based habitation, circuit design, software development, and city planning [Moran and Carroll 1994]. The IBIS framework supports decision making in complex systems by helping designers make explicit statements to describe their intent. These statements of rationale are useful both to the individual making the statement, and to other participants in the design process, because they focus discussion and help manage the problem.

An IBIS is a network of nodes and the links between them (Figure IV-1). There are three kinds of nodes*: issues*, or questions about the outcome of a design; *positions,* or values responding to the issues; and *arguments,* which provide justification for the position. A position or argument may be related to more than one issue, and issues may respond to other issues. The result is a non-hierarchical network, such as the illustration shown in Figure IV-1.

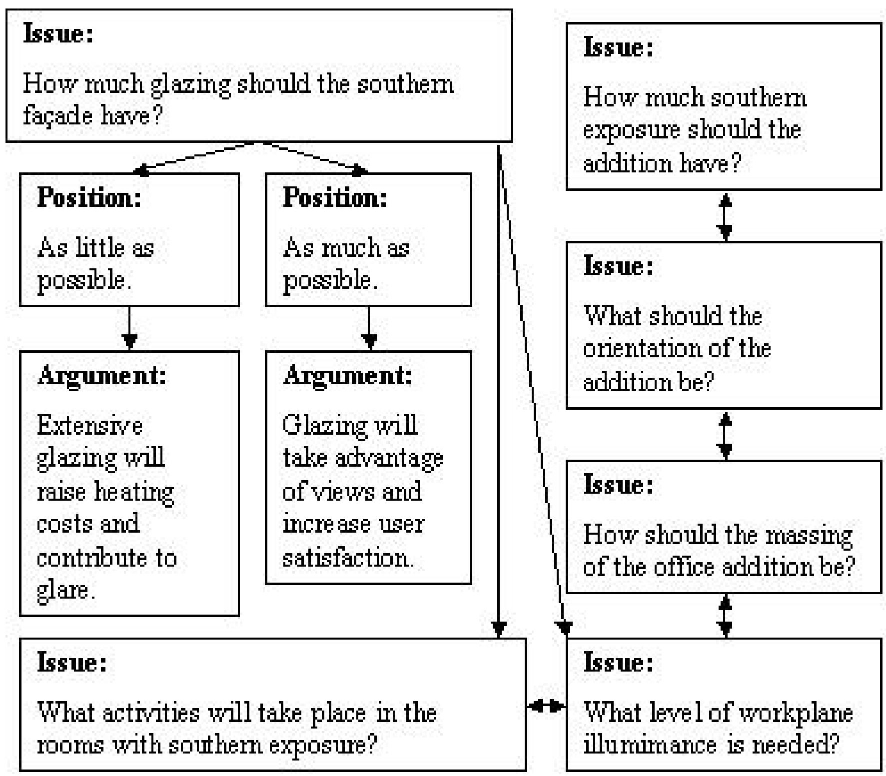


Figure IV-1. Example of an IBIS diagram, showing the relations among Issues, Positions and Arguments.

Advantages to Integrating an IBIS into the BDA

There are many advantages to integrating an IBIS into the BDA software. First, the IBIS can help clarify ambiguities in the communication process. Because building design is complex, many participants with varied backgrounds participate in the process. A prescribed format for communications can reduce confusion among parties. Second, an IBIS can also be a means of conflict detection. In a distributed decision-making environment, having a common representation of the problem can help multiple participants understand how their decisions affect each other's work. Third, an IBIS can provide a link between the values of particular parameters and intent. If a designer specifies a particular glazing material, it may be because she believes that material to have the highest R-value in its price range. Making the link between parameters, such as cost and R-value, and the material, allows others with specialized knowledge to propose alternative materials, which meet her criteria. Finally, an IBIS can provide institutional memory for a project. Because the current nature of work suggests workers spend less time in one position than in previous decades, the need to record experiential knowledge of a project in a central location can improve project management and efficiency by avoiding past mistakes. Figure IV-2 shows an updated version of the IBIS diagram showing how the issues, positions, and arguments can be integrated with the existing BDA software modules.

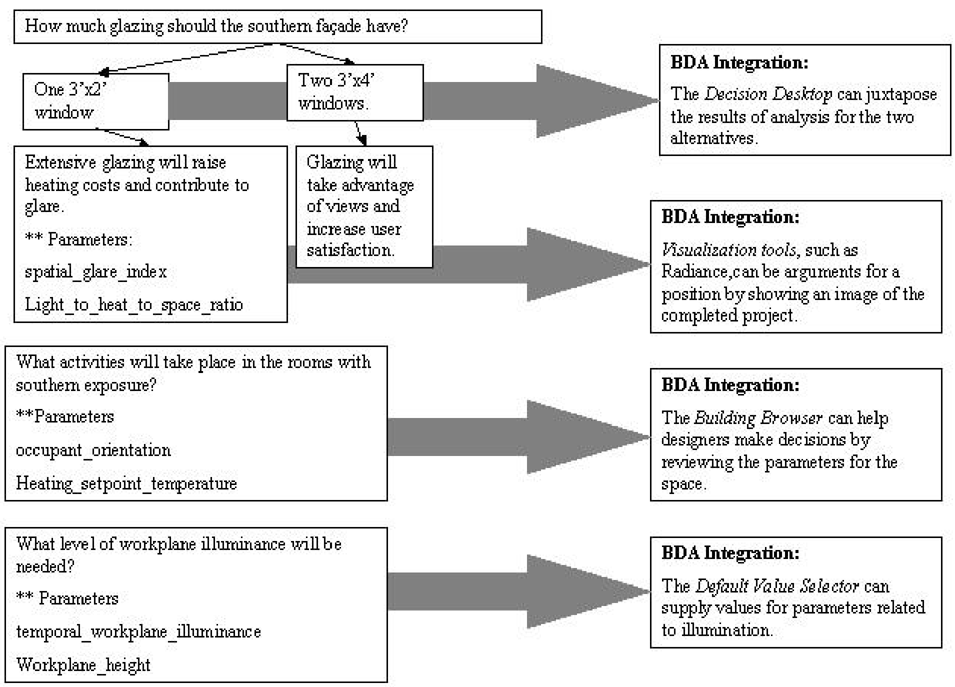


Figure IV-2. Interaction between Modules of a BDA-Based IBIS.

Approach to Integration: Strategies

Our approach to implementing an IBIS into the BDA environment is to aid the designer in developing a *strategy* for the project. A strategy is an over-arching direction driving design development, and the concept is common in architectural practice. In our proposed integration, the strategy is the basic unit for recording and ordering design rationale. A strategy is described in terms of desired performance of a project (one or more performance parameters), and it acts as a tool for thinking about the realtionships between deign paramteres already present in the BDA. Figure IV-3 shows the relationship between a strategy and its compositie values.

As an example, a strategy may be “to increase the uniformity of the spatial distribution of daylight in a light shelf.” The light shelf will have particular dimensions, position and surface color, be part of a particular window, with a particular ground reflectance in front of the window. If one of these design parameters does not have the “specific” value then the strategy falls apart. An argument for the value of a particular parameter can only stand when then rest of the parameters that comprise the strategy have specific values. Some parameters may be more important than others in a strategy, depending on their effect on the value of the performance variable being addressed. Such dependencies can be determined through sensitivity analyses, and be used to strengthen or weaken arguments.

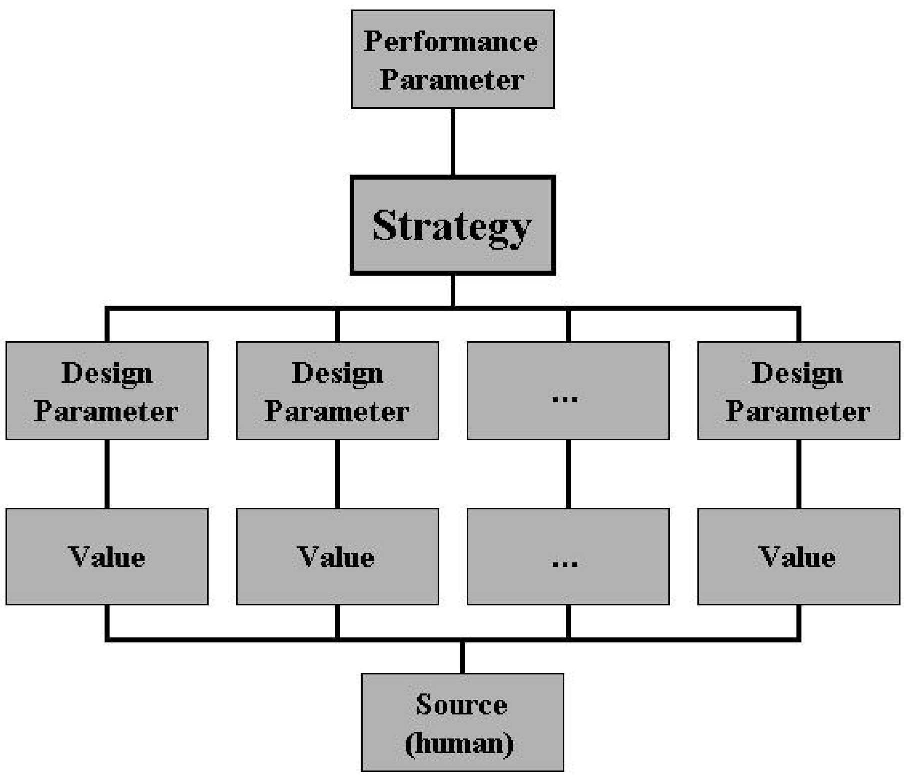


Figure IV-3. Definition of "Strategy" as a set of values for a set of design parameters, all of which, together, are meant to contribute towards meeting performance goals.

The BDA already provides users with a variety of tools for analysis and visualization. As part of our effort to integrate the IBIS with the BDA, we want to be able to use the output from the various modules of the BDA as part of a strategy, instead of relying only on text-based rationale entered by the designer. Within a strategy, the set of values of the design parameters can have the same, or different sources. For example, the designer may add textual rationale explaining a material choice, or use an image from a visualization to support a particular parameter of work-plane illuminance. In addition to parameters provided by the designer, the results of processes may also become elements of a strategy. For example, the source of the descriptive parameter “work-plane height” may be the result of the Default Value Selector while the result of simulations run by DOE-2 may provide other parameter values. In this example, the value of the parameters can come from either the human designer, or result from a process by a BDA module. Figure IV-4 shows the proposed expansion to the BDA meta-schema to address IBIS data needs.

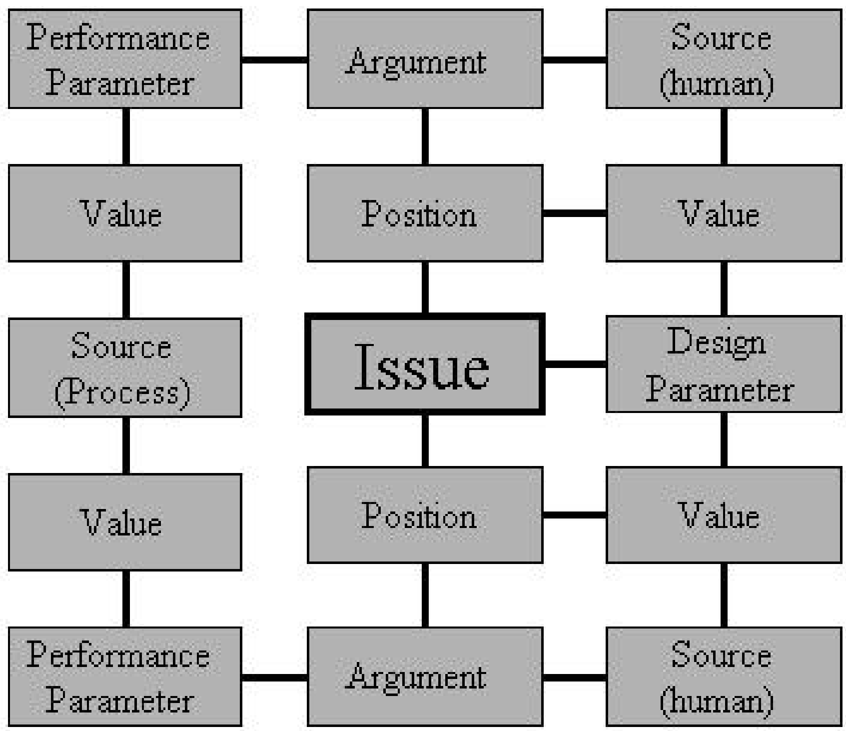


Figure IV-4. Partial view of an expanded BDA Meta-Schema that includes IBIS objects.

User Studies

As part of our review of implemented IBIS's, we examined what elements contributed to their overall success with users. How well an IBIS, or any new software, responds to the current work practices of its users is a major factor in how successful the system will be. To better understand the work practices and needs of potential users of the integrated BDA-IBIS environmnet, we conducted task analysis and user studies wth architects. The prpose of user studies was to learn more about how architects develop strategies in order to create plausible scenaria for the BDA-IBIS system would be used. We studied how architects developed strategies in the early phases of their design processes by observing architects designing and by recording their spoken design rationale as they worked on three brief sketch problems on issues related to energy efficiency. The sample tasks were to increase natural light penetratin into an office, redesign a building with an atrium to be more energy efficient, and add a residential facility to a children's hospital.

The architects surveyed were familiar with the concept of a strategy and said they worked in similar terms already. All agreed that strategies emerged during the early, conceptual phase of design development, rather than being added later. Strategy development in the early phase typically involves including multiple parameters to achieve the same goal. The participants gave several reasons for this including "piling it [repetitive elements] on to make sure the client gets the concept" and expecting some of the alternatives to be stripped away by clients or engineers. The expectation that some of the desired parameters would be removed suggests two kinds of interaction with the strategies: need to prioritize parameters based on relative contribution to the strategy, or "most bang for the buck;" and need to understand how interactions between parameters aggregate to support the strategy.

Examples of stratgies developed by architects during the user studies include metaphors, such as a designer adding a residential facility to a hospital who called her strategy "a village around a church" to convey a group of low residentail buildings around a dominant form (the hospital). Another strategy for the same project included "a symbiotic relationship" meaning that the hospital would give extra power to the residences, and the residences would provide life-giving energy to the patients in the hospital. Strategies may not be metaphors, they can also be concepts such as "a show-case energy efficienct building" or "something constructable during the short summer building season."

The rationale the designers gave as they described their strategies forms the basis of anticipated user interactions with the BDA-IBIS system. The descriptions below paraphrase the designers' descriptions of their strategies. These descriptions are then translated into functional interactions with existing system components. In all cases recording rationale in the form of a strategy would require interaction with a new user interface element, the *strategy manager*.

System interaction

The following user tasks show how a designer would interact with the various modules of the BDA while developing a strategy.

Add Rationale

Strategy Manager	add text explaining a decision
Decision Desktop	take an image to use as support for a strategy
Building Browser	get help selecting a value for a parameter
Visualization Module	add image to support strategy
Schematic Graphic Editor	ask for help selecting a value for a parameter

Edit Rationale

Strategy Manager	add text refining or contradicting a decision
Building Browser	connect parameters to build strategy
Default Value Selector	update values due to change (in season, product, etc.)

Review Previous Rationale

Strategy Manager	get overview of elements with rationale attached
Decision Desktop	browsing to learn state of a project
Building Browser	search for issues added by others, browse to learn state of project
Default Value Selector	search for value based on past project

Visualize Issue-Base

Strategy Manager	see overview in two ways, graphical or list
Decision Desktop	view the elements that have rationale attached
Building Browser	view the elements that have rationale attached
Visualization Module	view the images that are used as rationale
Schematic Graphic Editor	view the elements that have rationale attached

Strategy Manager

We have prototyped this new component of the BDA to allow users to record their design rationale in the form of a strategy. The Strategy Manager shows two views of the rationale: a graphical image of links and nodes, and a textual outline. The purpose of the strategy manager is to allow the user to see: 1) which elements in a design have rationale attached, 2) which parameters are being used as rationale, and 3) the relationship between elements of rationale (Figure IV-5).

The design of the graphical user interface shown above was informed by a review of interface to other IBIS's (Moran and Carroll 1994) and the user studies of architects. Part of the development process includes creating storyboards of use scenaria detailing interaction with various parts of the Strategy Manager. Figure IV-6 shows an example of one use scenario. To develop this prototype further, we will need to get feedback from users to gauge how well these scenaria fit with their individual design needs.

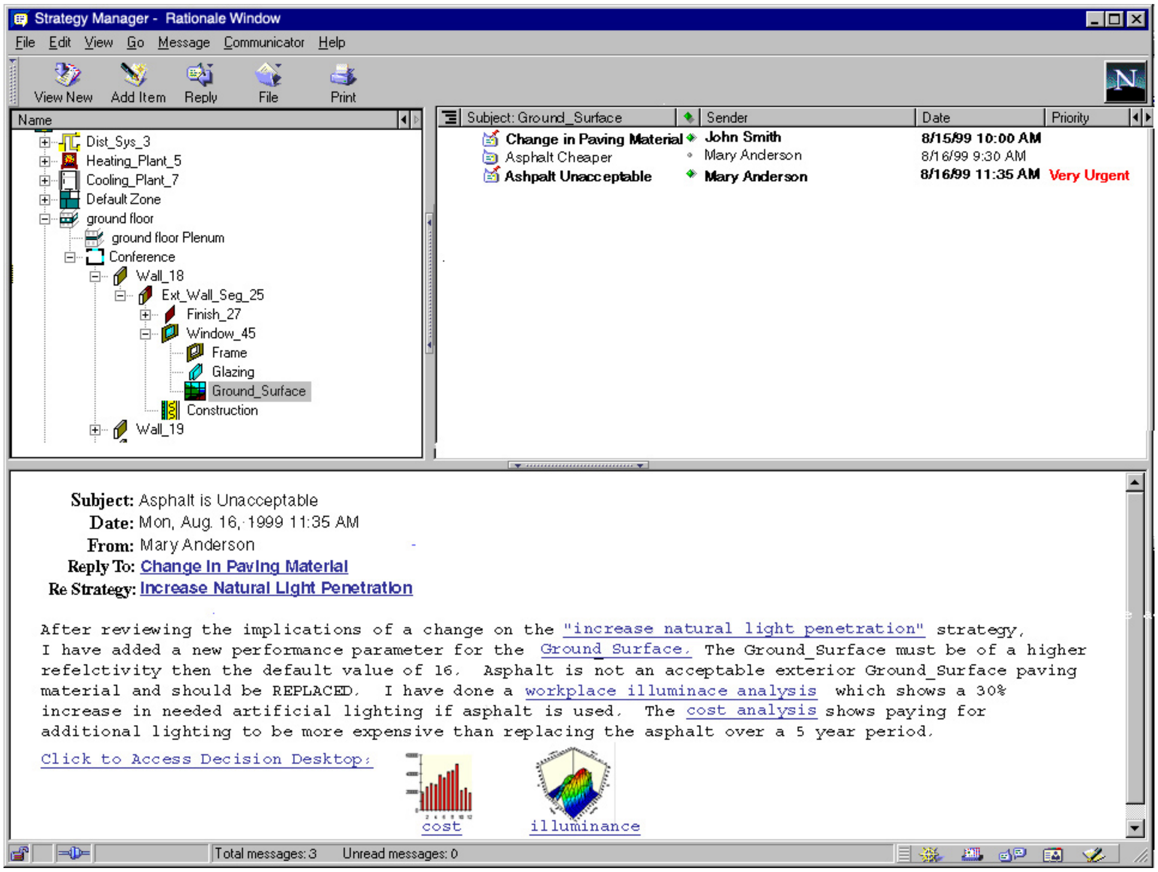


Figure IV-5. The strategy manager interface.

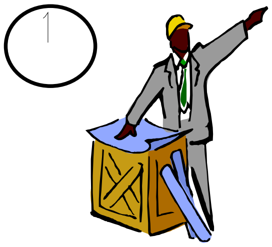
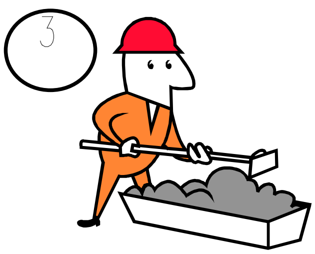
	Scene	System Interaction
	John, an architect making a site visit, notices that the exterior paving is a asphalt, not concrete, as specified. He wants to notify other team members of the change.	Use Strategy Manager to create new rationale attached to the paving outside the building.
	Mary, the architect in the home office, starts her day by seeing what's new with the project. When she sees that the paving material has changed, she calls the construction manager to figure out why this new material was installed. Then she needs to decide if asphalt is an acceptable alternative in this situation.	Use Strategy Manager to view graphical elements with rationale attached that she hasn't read. Edit textual rationale for paving choice to include the argument the construction manager gave for asphalt. Use the Building Browser to change the material to asphalt. She then uses the Decision Desktop to compare natural light penetration with concrete and asphalt outside.
	She decides the energy savings from using natural light outweighs the cost of replacing the exterior paving material. She wants to tell everyone that the current material is unacceptable because it doesn't meet desired performance criteria and must be replaced with something that does. The client agrees, and Bill makes the change.	Link to an external cost evaluation tool. Edit rationale in the strategy manager to include a position opposing the use of asphalt. Attach the output from the cost evaluator and the image showing natural light penetration from the Decision Desktop as arguments for her position. Modify strategy to "increase natural light penetration" to include a new performance parameter for ground_surface.

Figure IV-6. Sample user interaction scenario.